# The Regional Impacts of Climate Change

## An Assessment of Vulnerability

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# Africa

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# EXECUTIVE SUMMARY

Several climate regimes characterize the African continent; the wet tropical, dry tropical, and alternating wet and dry climates are the most common. Many countries on the continent are prone to recurrent droughts; some drought episodes, particularly in southeast Africa, are associated with El Niño-Southern Oscillation (ENSO) phenomena. Deterioration in terms of trade, inappropriate policies, high population growth rates, and lack of significant investment—coupled with a highly variable climate—have made it difficult for several countries to develop patterns of livelihood that would reduce pressure on the natural resource base. Under the assumption that access to adequate financing is not provided, Africa is the continent most vulnerable to the impacts of projected changes because widespread poverty limits adaptation capabilities.

*Ecosystems*: In Africa today, tropical forests and rangelands are under threat from population pressures and systems of land use. Generally apparent effects of these threats include loss of biodiversity, rapid deterioration in land cover, and depletion of water availability through destruction of catchments and aquifers. Changes in climate will interact with these underlying changes in the environment, adding further stresses to a deteriorating situation. A sustained increase in mean ambient temperatures beyond 1°C would cause significant changes in forest and rangeland cover; species distribution, composition, and migration patterns; and biome distribution. Many organisms in the deserts already are near their tolerance limits, and some may not be able to adapt further under hotter conditions. Arid to semi-arid subregions and the grassland areas of eastern and southern Africa, as well as areas currently under threat from land degradation and desertification, are particularly vulnerable. Were rainfall to increase as projected by some general circulation models (GCMs) in the highlands of east Africa and equatorial central Africa, marginal lands would become more productive than they are now. These effects are likely to be negated, however, by population pressure on marginal forests and rangelands. Adaptive options include control of deforestation, improved rangeland management, expansion of protected areas, and sustainable management of forests.

*Hydrology and Water Resources*: Of the 19 countries around the world currently classified as water-stressed, more are in Africa than in any other region—and this number is likely to increase, independent of climate change, as a result of increases in demand resulting from population growth, degradation of watersheds caused by land-use change, and siltation of river basins. A reduction in precipitation projected by some GCMs for the Sahel and southern Africa—if accompanied by high interannual variability—could be detrimental to the hydrological balance of the continent and disrupt various water-dependent socioeconomic activities. Variable climatic conditions may render the management of water resources more difficult both within and between countries. A drop in water level in dams and rivers could adversely affect the quality of water by increasing the concentrations of sewage waste and industrial effluents, thereby increasing the potential for the outbreak of diseases and reducing the quality and quantity of fresh water available for domestic use. Adaptation options include water harvesting, management of water outflow from dams, and more efficient water usage.

*Agriculture and Food Security*: Except in the oil-exporting countries, agriculture is the economic mainstay in most African countries, contributing 20–30% of gross domestic product (GDP) in sub-Saharan Africa and 55% of the total value of African exports. In most African countries, farming depends entirely on the quality of the rainy season—a situation that makes Africa particularly vulnerable to climate change. Increased droughts could seriously impact the availability of food, as in the Horn of Africa and southern Africa during the 1980s and 1990s. A rise in mean winter temperatures also would be detrimental to the production of winter wheat and fruits that need the winter chill. However, in subtropical Africa, warmer winters would reduce the incidence of damaging frosts, making it possible to grow horticultural produce susceptible to frosts at higher elevations than is possible at present. Productivity of freshwater fisheries may increase, although the mix of fish species could be altered. Changes in ocean dynamics could lead to changes in the migratory patterns of fish and possibly to reduced fish landings, especially in coastal artisinal fisheries.

*Coastal Systems*: Several African coastal zones—many of which already are under stress from population pressure and conflicting uses—would be adversely affected by sea-level rise associated with climate change. The coastal nations of west and central Africa (e.g., Senegal, The Gambia, Sierra Leone, Nigeria, Cameroon, Gabon, Angola) have low-lying lagoonal coasts that are susceptible to erosion and hence are threatened by sea-level rise, particularly because most of the countries in this area have major and rapidly expanding cities on the coast. The west coast often is buffeted by storm surges and currently is at risk from erosion, inundation, and extreme storm events. The coastal zone of east Africa also will be affected, although this area experiences calm conditions through much of the year. However, sea-level rise and climatic variation may reduce the buffer effect of coral and patch reefs along the east coast, increasing the potential for erosion.

A number of studies indicate that a sizable proportion of the northern part of the Nile delta will be lost through a combination of inundation and erosion, with consequent loss of agricultural land and urban areas. Adaptation measures in African coastal zones are available but would be very costly, as a percentage of GDP, for many countries. These measures could include erection of sea walls and relocation of vulnerable human settlements and other socioeconomic facilities.

*Human Settlement, Industry, and Transportation*: The main challenges likely to face African populations will emanate from extreme climate events such as floods (and resulting landslides in some areas), strong winds, droughts, and tidal waves. Individuals living in marginal areas may be forced to migrate to urban areas (where infrastructure already is approaching its limits as a result of population pressure) if the marginal lands become less productive under new climate conditions. Climate change could worsen current trends in depletion of biomass energy resources. Reduced stream flows would cause reductions in hydropower production, leading to negative effects on industrial productivity and costly relocation of some industrial plants. Management of pollution, sanitation, waste disposal, water supply, and public health, as well as provision of adequate infrastructure in urban areas, could become more difficult and costly under changed climate conditions.

*Human Health*: Africa is expected to be at risk primarily from increased incidences of vector-borne diseases and reduced nutritional status. A warmer environment could open up new areas for malaria; altered temperature and rainfall patterns also could increase the incidence of yellow fever, dengue fever, onchocerciasis, and trypanosomiasis. Increased morbidity and mortality in subregions where vector-borne diseases increase following climatic changes would have far-reaching economic consequences. In view of the poor economic status of most African nations, global efforts will be necessary to tackle the potential health effects.

*Tourism and Wildlife*: Tourism—one of Africa's fastest-growing industries—is based on wildlife, nature reserves, coastal resorts, and an abundant water supply for recreation. Projected droughts and/or reduction in precipitation in the Sahel and eastern and southern Africa would devastate wildlife and reduce the attractiveness of some nature reserves, thereby reducing income from current vast investments in tourism.

*Conclusions*: The African continent is particularly vulnerable to the impacts of climate change because of factors such as widespread poverty, recurrent droughts, inequitable land distribution, and overdependence on rain-fed agriculture. Although adaptation options, including traditional coping strategies, theoretically are available, in practice the human, infrastructural, and economic response capacity to effect timely response actions may well be beyond the economic means of some countries.

## 2.1. Introduction

This chapter focuses on the potential impacts of climate change on ecosystems, natural resources, and various socioeconomic sectors of mainland Africa. To the extent permitted by the literature, it describes the functions and current status of a number of key resource sectors and ecosystems; the ways in which these systems would respond to changes in climatic conditions; options for adaptation to projected changes in climate; and the vulnerability of each system or sector, taking into account adaptation options as well as impediments to their implementation. Downing (1992, 1996) suggests that vulnerability is an aggregate measure of human welfare that integrates environmental, social, economic, and political exposure to a range of potentially harmful perturbations or threats. Vulnerability varies spatially and temporally for different communities, although they may face the same risk (Eele, 1996). Feasible strategies for coping with future climate changes therefore must be rooted in a full understanding of the complex structure and causes of present-day social vulnerability, through an understanding of vulnerability to climatic variability on seasonal to interannual time scales.

Although Africa, of all the major world regions, has contributed the least to potential climate change because of its low per capita fossil energy use and hence low greenhouse gas emissions, it is the most vulnerable continent to climate change because widespread poverty limits capabilities to adapt. The ultimate socioeconomic impacts of climate change will depend on the relative resilience and adaptation abilities of different social groups. In general, the commercial sector and high-income households in communal areas are better equipped to adjust adequately and in a timely fashion. Much will depend on the coping abilities and mechanisms used by governments and households over the next 50 years or so. Such abilities are determined by political stewardships. If the region manages to achieve reasonable economic growth, the prospects for proper adjustments to climate change are much better than if economic stagnation prevails (Hulme, 1996b).

### 2.1.1. *Physical Geography*

Africa has a total land area of 30,244,000 km$^2$. Countries considered in this chapter are listed in Box 2-1, and socioeconomic data are provided in Annex D.

Africa's physical features include a series of plateaus, higher in the east and gradually declining toward the west. The general elevation is relieved by great shallow basins and their river systems; by the deep incision of the 6,400-km Great Rift Valley; and by often-magnificent volcanoes, fault blocks, and inselbergs. Figure 2-1 shows capitals, other major cities, and elevations. The highest point is Mount Kilimanjaro (5,894 m); the lowest point is in the Qattara Depression, at 132 m below sea level. Africa's vast plateaus are broken only by a few rather low mountain ranges—of which the outstanding ones are the Atlas, Ahaggar, Cameroons, Tibetsi, and Ethiopian and eas African highlands, as well as the Drakensberg Mountains. I east Africa are (in addition to Kilimanjaro) Mount Keny (5,199 m), the Ruwenzoris (5,120 m), and Mount Elgon (4,32 m) (Pritchard, 1985).

The African continent encompasses a rich mosaic of ecological settings. Together these ecosystems harbor a wealth o economically and biologically important resources, fron individual species to productive habitats (Huq *et al.*, 1996) One quarter of Africa is hyper-arid desert; one third is in th humid climate zone; and the remainder of the continent i dryland, consisting of arid, semi-arid, and dry subhumi areas (UNEP, 1992). These drylands are home to about 40 million people—two-thirds of the continent's total population. Recurrent droughts have long been a permanent featur of life throughout the drylands of Africa. Over the past 3 years or so, however, unusually severe and/or prolonge droughts in these drylands have seriously affected agricultur and wildlife and caused many deaths and severe malnutrition In some areas, desertification has accompanied thes droughts, although the processes leading to desertification ar much more varied than climate alone. Currently, 36 countrie in Africa are affected by recurrent drought and some degre of desertification (UNEP, 1992). The risk of drought is highest in the Sudano-Sahelian belt and in southern Afric (Nicholson *et al.*, 1988).

**Box 2-1. The Africa Region**

Algeria
Angola
Benin
Botswana
Burkina Faso
Burundi
Cameroon
Central African Republic
Chad
Congo
Cote d'Ivoire
Democratic Republic of
  Congo (DRC)
  (formerly Zaire)
Djibouti
Egypt
Equatorial Guinea
Eritrea
Ethiopia
Gabon
Ghana
Guinea
Guinea-Bissau
Kenya
Lesotho
Liberia
Libya
Madagascar
Malawi
Mali
Mauritania
Morocco
Mozambique
Namibia
Niger
Nigeria
Reunion
Rwanda
Senegal
Sierra Leone
Somalia
South Africa
Sudan
Swaziland
Tanzania
The Gambia
Togo
Tunisia
Uganda
Zambia
Zimbabwe

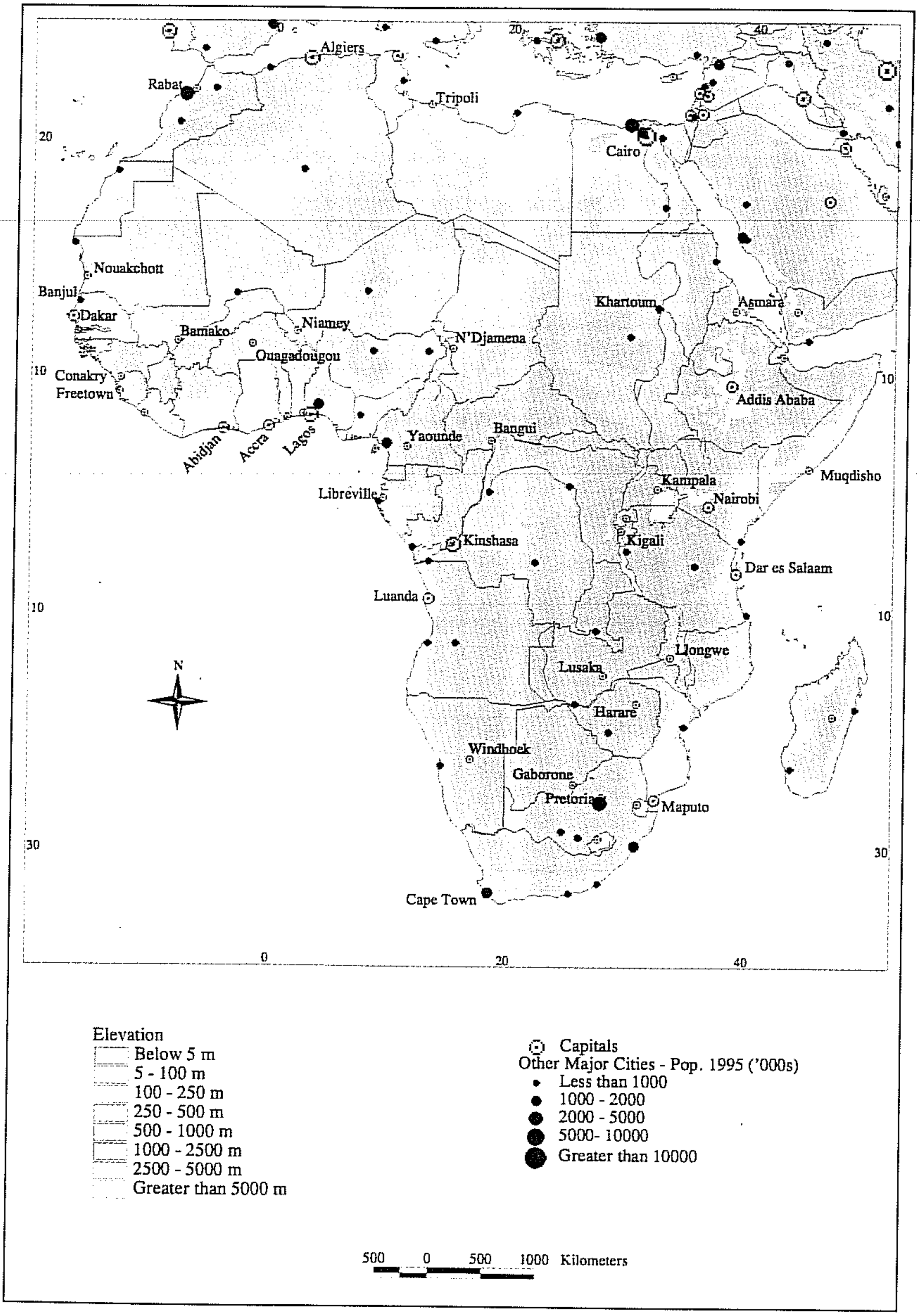


**Figure 2-1:** The Africa region [compiled by the World Bank Environment Department Geographic Information System (GIS) Unit; see Annex E for a color rendition].

### 2.1.2. *People and Natural Resources*

The population of Africa is approximately 650 million (World Bank, 1995b). About two-thirds of the population lives in rural areas and derives its main income from agriculture. In some countries—such as Burkina Faso, Ethiopia, Malawi, and Uganda—rural population makes up more than 80% of the total. Agriculture is the fundamental economic activity in these countries; although it accounts on average for only about 20–30% of GDP, agriculture contributes the largest share of total exports (Cleaver and Schreiber, 1994).

Cultivated land per capita varies considerably across the continent, reflecting the uneven distribution of population (for example, low density in the Congo basin but high in the east African Highlands) as well as low levels of technology and the unsuitability of wide areas for farming. Dependence on shifting cultivation makes the area needed for cropland high. Scarcity of good land, coupled with soil degradation and low levels of inputs and technology, results in increasing deficits in food production. The predominance of rain-fed subsistence agriculture and, across southern Africa, overdependence on (water-demanding) maize has helped ensure that food security for most of the continent is inextricably linked to the quality of each rainy season. In dryland regions, crop and livestock production are extremely susceptible to seasonal rainfall variability and, as a result, have shown considerable volatility in recent years. Drought shock, however, extends well beyond the confines of agriculture (crop) and livestock production, partly because of the important roles these two sectors play in the overall economies of many African states. Crop and livestock production are major employers and make significant contributions to GDP and export earnings. They also are major sources of raw materials for industries such as textiles, food processing, and fuel refining. On the other hand, they are major markets for other industries such as machinery, animal feeds, fuel, and fertilizer producers (Gibberd *et al.*, 1996).

Of the 30 poorest countries of the world, 22 are African (World Bank, 1996). The average income level in sub-Saharan Africa in 1993 was $520 per capita, and the average growth rate per capita was negative (-0.8% per year from 1980 to 1993). By the year 2000, the number of poor in Africa is projected to increase to an estimated 265 million—which would represent more than 40% of the continent's population (World Bank, 1990). In Africa, poverty is linked to the environment in complex ways, particularly in economies that are based on exploitation of natural resources. Degradation of these resources reduces the productivity of poor persons, who most rely on them, and makes poor communities even more susceptible to extreme events (whether meteorological, economic, or political in origin) (World Bank, 1996). Poverty is exacerbated by a demographic profile that continues to record an annual population growth rate of just under 3%, the highest in the world (WRI, 1994). As a result, the population in many African countries will continue to double every 20 to 30 years, well into the 21st century. However, the high incidence of incurable diseases—such as malaria, human immunodeficiency virus (HIV), and hepatitis B—may modify this estimate.

## 2.2. Regional Climate

The continent of Africa is characterized by several climati regimes and ecological zones. All parts of the continent, excep the Republic of South Africa, Lesotho, and the Mediterranea countries north of the Sahara, have tropical climates. Thes tropical climates may be divided into three distinct climati zones: wet tropical climates, dry tropical climates, and alternating wet and dry climates (Huq *et al.*, 1996).

Several comprehensive descriptions of the climates of Afric exist, most notably those of Thomson (1965) and Griffiths (1972). Surveys of African rainfall have been carried out by Newell *et al.* (1972), Kraus (1977), Klaus (1978), Tyson (1986), and Nicholson (1994b). These researchers agree that summer rainfall maxima, which are dominant over most of Africa, are controlled primarily by the Inter-Tropical Convergence Zone (ITCZ). Over land, the ITCZ tends to follow the seasonal march

**Box 2-2. Africa's Natural Resources, Economy, and Political Environment**

African economies have made relatively low levels of investment in infrastructure and directly productive capital goods—and hence continue to rely heavily on natural capital (natural resources). This natural capital is at risk because poverty and high population growth often induce land degradation and deforestation—which in turn lead to growing food insecurity and loss of biodiversity. This pattern contributes to migration into rural areas that often are less suitable for agricultural expansion and to urban areas with inappropriate physical, social, and economic infrastructure. The process also contributes to population growth by creating an incentive for large families: Adding family labor becomes one way of coping with the increasing time costs of gathering fuel and water and clearing new land. The severity of this population-agriculture-environment nexus is compounded by low investment in human capital (human resource development), which often restricts individuals to continued reliance on unskilled labor and short-term exploitation of natural resources (the land) as the only feasible survival options.

Although Africa's youthful population represents future social capital, a great deal of investment in terms of education, training, and skills development will be required to ensure its full productivity in the next decade and beyond. Particular attention will need to be paid to capacity-building in information technology to better prepare African societies for efficient, sustainable management of the continent's fragile resources. In addition, the region's political structures, which determine decision making in resource allocation and consumption, will have to be stabilized.

of the sun and oscillates between the fringes of the Sahara in boreal summer and the northern Kalahari desert in the austral summer. The latitude zones of these arid and semi-arid deserts demarcate the tropics from the subtropics. Rainfall in the subtropics is modulated by mid-latitude storms, which may be displaced Equator-ward in winter. Further modification of these broad patterns is provided by natural features such as lakes and mountains, and by the influence of ocean currents. The poleward extremes of the continent have extratropical influences associated with mid-latitude synoptic disturbances, resulting in significant winter rainfall (Griffiths, 1972).

In general, surface air temperatures over most of Africa display a high degree of thermal uniformity, spatially and seasonally (Riehl, 1979). The extreme north and south of the continent, however, experience cold frontal systems that quasi-regularly introduce abrupt air mass changes. Temperatures there are more variable in response to a large annual cycle of insolation and the effects of seasonally varying air masses and winds. Mean temperature trends over the past 100 years, averaged over continental Africa, are shown in Figure 2-2. The highland areas of eastern and southern Africa are substantially cooler than lowland regions, and there is evidence that recent warming trends may have been exaggerated in these mountain areas (Hulme, 1996a).

Rainfall over Africa exhibits high spatial and temporal variability (see Figures 2-3 and 2-4). Mean annual rainfall ranges from as low as 10 mm in the innermost core of the Sahara to more than 2,000 mm in parts of the equatorial region and other parts of west Africa (Figure 2-4). The rainfall gradient is largest along the southern margins of the Sahara—the region known as the Sahel—where mean annual rainfall varies by more than 1,000 mm over about 750 km. This tight rainfall gradient means that relatively small changes in the position of the ITCZ can have large consequences for rainfall in the Sahel; thus, this region is a sensitive indicator of climate change in Africa. Coefficients of rainfall variability in Africa exceed 200% in the deserts; they are about 40% in most semi-arid regions, and between 5% and 20% in the wettest areas (Figure 2-3).

Most policymakers now recognize drought as a normal feature of Africa's climate and acknowledge that its recurrence is inevitable. Widespread occurrences of severe drought during the past three decades have repeatedly underscored the vulnerability of developed and developing societies to its ravages in Africa. Although the variability of African climate is inevitable, loss of human life and economic disruption associated with extreme climatic fluctuation can be lessened by advance warning. Recent scientific advances in understanding the climate system and breakthroughs in predictive capabilities on seasonal time scales provide an opportunity to reduce the vulnerability of human societies by planning for previously unexpected variations from mean climatic conditions. Current forecasting capabilities, although by no means perfect, provide a better indication of climatic conditions that are expected to prevail during the next season or two than simply assuming that rainfall and temperature will be normal (Bonkoungou, 1996).

### 2.2.1. *African Climate Trends and Projections*

Temperature and precipitation trends are reviewed in Annex A of this report. Rainfall trends—especially over the past 30 years or so—have had a very large bearing on socioeconomic development of the continent because most activities are agriculturally based (Serageldin, 1995).

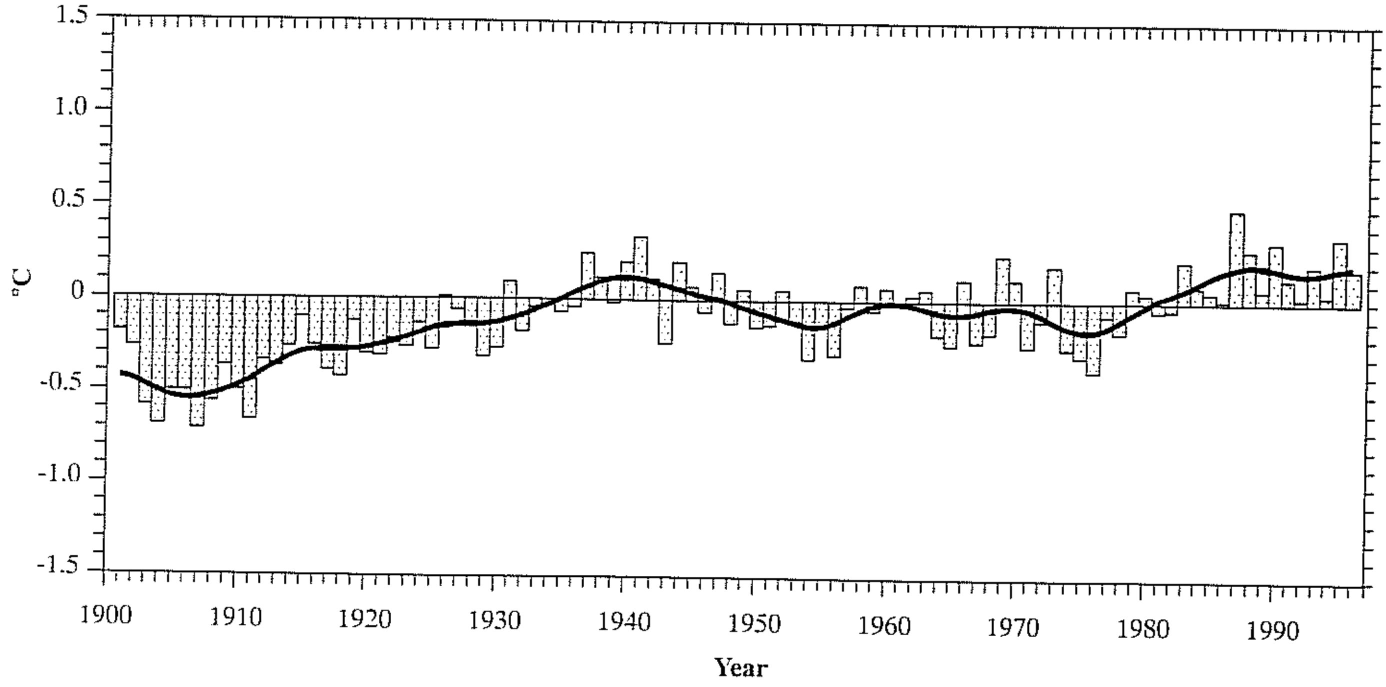


**Figure 2-2:** Observed annual temperature changes in Africa (see Annex A).

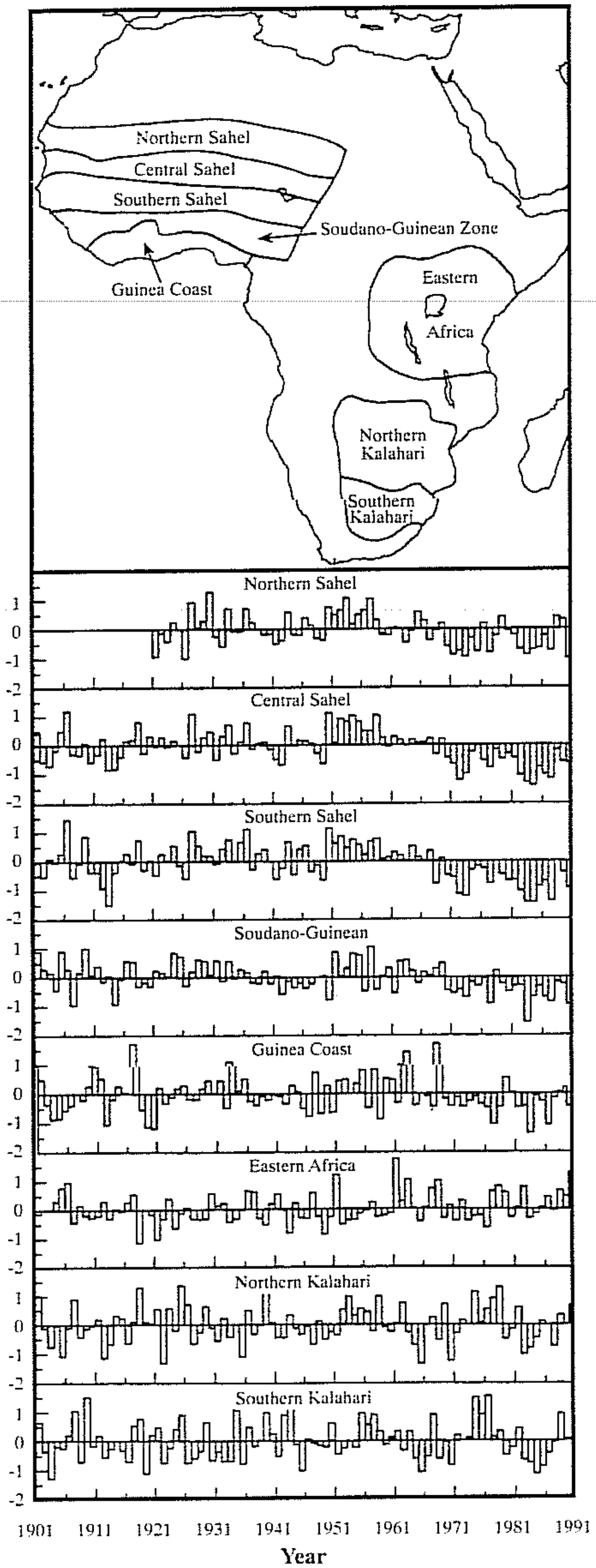


**Figure 2-3**: Rainfall fluctuations for select areas of Africa, expressed as a regionally averaged standard departure (Nicholson, 1993).

Uncertainties in GCMs make deriving regional climate chang predictions impossible (see Annex B of this report for an assessment of regional projections of climate change). Therefore, it i important to interpret model outputs in the context of thei uncertainties and to consider them as potential scenarios o change for use in sensitivity and vulnerability studies. In IPCC (1990), IPCC (1996), and Hernes *et al.* (1995), the Sahe (10–20°N, 20–40°E) was selected as a study region for purposes of inter-comparing GCM outputs. Since then, severa approaches to subregional climate projection have been developed at national levels (e.g., Joubert, 1995; Ringius *et al.* 1996); several others have been developed under the U.S Country Studies Program (USCSP, 1996).

Although most initial climate change simulations used GCMs an increasing number of climate-modeling centers have use regional climate models (RCMs). RCMs rely on similar physical representations of atmospheric processes as GCMs but operate at a much finer spatial resolution—typically 50 km—ove limited domains. Little climate change work using RCMs nested within GCMs has been completed as yet for Africa (Ringiu *et al.*, 1996), so it remains necessary to rely on extractin regional results for Africa from GCM climate change experiments. A selection of such results is summarized in Box 2-3.

## 2.3. Vulnerabilities and Potential Impacts for Key Sectors

### 2.3.1. *Terrestrial Ecosystems*

#### 2.3.1.1. *Introduction*

Numerous schemes have been used to describe Africa's vegetation and ecosystems. White's (1983) classification system i used here, aggregated (after Justice *et al.*, 1994) to show th rainforest in central Africa (unmarked) and two major categories of woodland savannas divided by moisture and nutrien level: broad-leafed, nutrient-poor, moist savannas; and fine leafed, nutrient-rich, arid savannas (Figure 2-5). This aggregation summarizes current understanding of the role of soil nutrients and moisture on vegetation distribution in Africa, especially in savannas (Scholes and Walker, 1993). The broad-leafe savannas include the extensive miombo woodlands of centr and southern Africa. Nutritionally poor soils support only low quality grass for grazing, so the numbers of large herbivores low in miombo and other broad-leafed savannas (Frost, 1996 The fine-leafed savannas include acacia-dominated thor woodlands, which have higher-quality grass and so suppo large numbers of large herbivores; these areas constitute th main rangeland region.

Africa is composed essentially of woodlands and grassland with rainforests occupying only about 7% of the land are Africa's rainforests represent slightly less than one-fifth of th total remaining rainforest in the world; Asia and Latin Americ contain the rest (Sayer *et al.*, 1992). Only about a third Africa's historical forest extent remains, with west Africa forests being lost faster than those of any other region. Annual deforestation rates average 0.7% per annum (FAO, 1997).

WRI (1996) indicates that only 8% (0.5 million km$^2$) of Africa's regional forest remains as "frontier forest." (Frontier forest is essentially natural/primary forest of sufficient size to support ecologically viable populations of indigenous species.) More than 90% of west Africa's original forest has been lost, and only a small part of what remains qualifies as frontier forest. Of the remaining forest, 77% is under moderate or high threat from logging and commercial hunting to meet growing urban demand for bushmeat. Demands on forests also have escalated in some regions (e.g., as a result of civil unrest that has pushed hundreds of thousands of people into previously intact forest).

Many studies of African ecosystems emphasize particular vegetation types—savanna grasslands, miombo woodlands, mopane woodlands, rangelands, or rainforest—or particular regions: the Sahel, sub-Saharan Africa, or the Southern African Development Community (SADC). In general, the structure of Africa's vegetation is determined by climate at the large scale, then soil type (texture) and nutrient levels at the local scale (Scholes and Walker, 1993). Fire and herbivory are important disturbance factors. Increased moisture in drier areas will likely result in a complex set of feedbacks between nutrients, fire occurrence, decomposition, and competing vegetation.

Increased variability in rainfall and changes in temperature will likely disrupt key ecosystem processes such as phenology and will influence insect pests and diseases in mostly unknown ways. Direct effects on pests will involve disruption of insect life cycles or creation of more suitable conditions for new pests (or for old pests to expand their territory). Ticks, tsetse flies, and locusts are notable examples of serious insect pests in Africa. Although a lot of work has been done to study these insects, a lot remains to be done, especially in relation to how climate change may impact them.

### *2.3.1.2. Climatic Driving Forces*

Of the many climatic factors that are important for plant growth, among the most significant in relation to climate change are temperature, water availability (determined by precipitation and soil characteristics, as well as other meteorological variables), and carbon dioxide ($CO_2$) concentrations. Consideration of the effects of climate change requires examination of the direct effects of changes in $CO_2$ concentrations and climate variables on the growth of plants, as well as the ways in which these direct effects are modified by soil feedbacks and biological interactions among different organisms.

The effects of temperature changes will vary in different subregions and ecosystems. An increase in temperatures will reduce the incidence of frost damage in areas where this damage occurs and widen the potential geographical range of species that are limited by minimum temperatures. The extent of effects of higher temperatures on African vegetation (e.g., effects on respiration rates, membrane damage) is largely uncertain. Temperature is known to interact with $CO_2$ concentration, so expected increases in respiration resulting from a temperature increase alone may be offset or even reduced by higher $CO_2$ concentrations (Wullschleger and Norby, 1992).

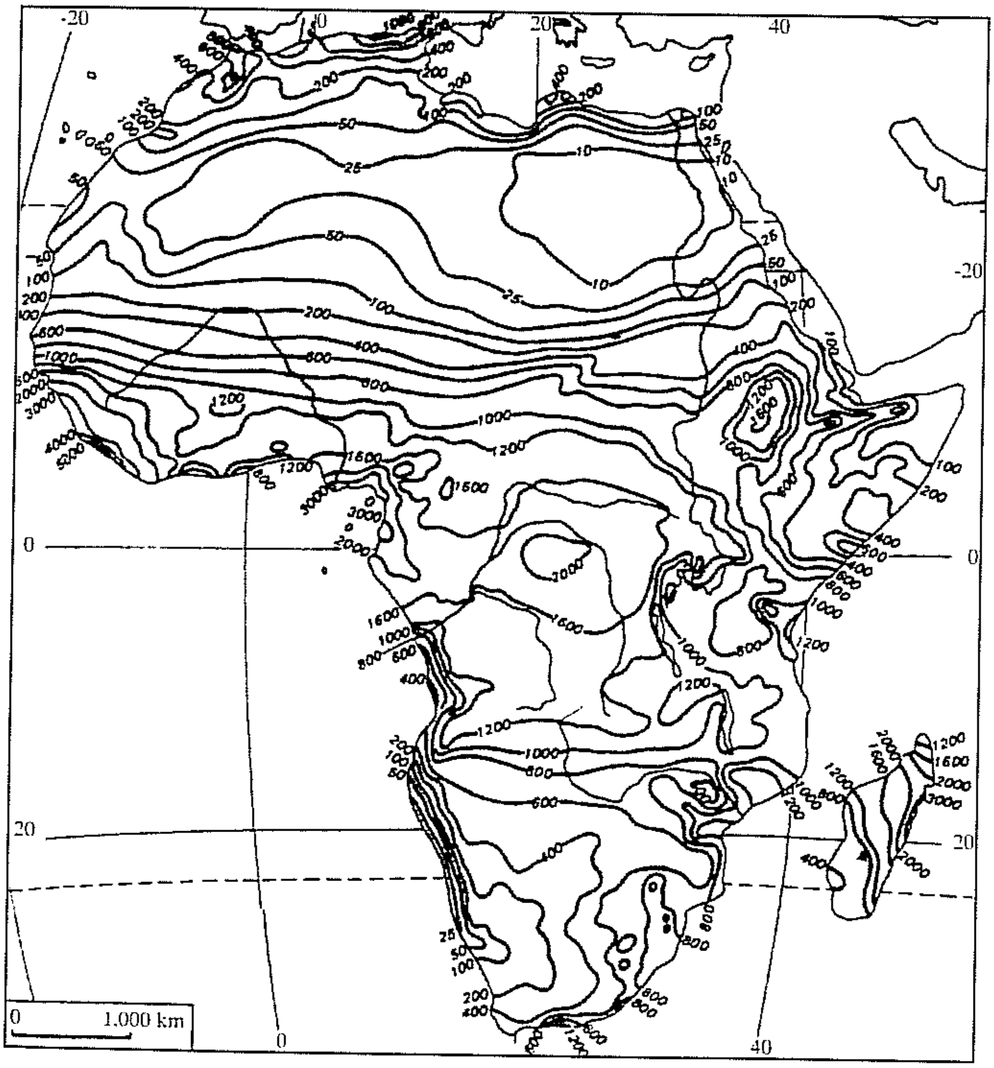


**Figure 2-4**: Mean annual precipitation (mm) in Africa (Martyn, 1992).

### Box 2-3. Climate Scenarios

With respect to temperature, land areas may warm by 2050 by as much as 1.6°C over the Sahara and semi-arid parts of southern Africa (Hernes *et al.*, 1995; Ringius *et al.*, 1996). Equatorial countries (Cameroon, Uganda, and Kenya) might be about 1.4°C warmer. This projection represents a rate of warming to 2050 of about 0.2°C per decade. Sea-surface temperatures in the open tropical oceans surrounding Africa will rise by less than the global average (i.e., only about 0.6–0.8°C); the coastal regions of the continent therefore will warm more slowly than the continental interior.

Rainfall changes projected by most GCMs are relatively modest, at least in relation to present-day rainfall variability. In general, rainfall is projected to increase over the continent—the exceptions being southern Africa and parts of the Horn of Africa; here, rainfall is projected to decline by 2050 by about 10%. Seasonal changes in rainfall are not expected to be large; Joubert and Tyson (1996) found no evidence for a change in rainfall seasonality among a selection of mixed-layer and fully coupled GCMs. Hewitson and Crane (1996) found evidence for slightly extended later summer season rainfall over eastern South Africa (though nowhere else), based on a single mixed-layer model prediction. Great uncertainty exists, however, in relation to regional-scale rainfall changes simulated by GCMs (Joubert and Hewitson, 1997). Parts of the Sahel could experience rainfall increases of as much as 15% over the 1961–90 average. Equatorial Africa could experience a small (5%) increase in rainfall. These rainfall results are not consistent: Different climate models, or different simulations with the same model, yield different patterns. The problem involves determining the character of the climate change signal on African rainfall against a background of large natural variability compounded by the use of imperfect climate models.

Projected temperature increases are likely to lead to increased open water and soil/plant evaporation. Exactly how large this increased evaporative loss will be would depend on factors such as physiological changes in plant biology, atmospheric circulation, and land-use patterns. As a rough estimate, potential evapotranspiration over Africa is projected to increase by 5–10% by 2050. Little can be said yet about changes in climate variability or extreme events in Africa. Rainfall may well become more intense, but whether there will be more tropical cyclones or a changed frequency of El Niño events remains largely in the realm of speculation.

Changes in sea level and climate in Africa might be expected by the year 2050. Hernes *et al.* (1995) project a sea-level rise of about 25 cm. There will be subregional and local differences around the coast of Africa in this average sea-level rise—depending on ocean currents, atmospheric pressure, and natural land movements—but 25 cm by 2050 is a generally accepted figure (Joubert and Tyson, 1996). For Africa south of the Equator, simulated changes in mean sea-level pressure produced by mixed-layer and fully coupled GCMs are small (~1 hPa)—smaller than present-day simulation errors calculated for both types of models (Joubert and Tyson, 1996). Observed sea-level pressure anomalies of the same magnitude as simulated changes are known to accompany major large-scale circulation adjustments associated with extended wet and dry spells over the subcontinent.

In most of Africa, water availability is projected to have the greatest impact on plant processes. Individual species are adapted to particular water regimes and may perform poorly and possibly die out in conditions to which they are poorly adapted (e.g., Hinckley *et al.*, 1981). The effects of climate change will vary—depending, for example, on how particular plant types use water (water-use efficiency, WUE) or the amount of water available in the soil. Plants are grouped into $C_3$, $C_4$, and CAM plant types depending on how the process of photosynthesis takes place (see IPCC 1996, WG II, Section A.2.2). $C_3$ plants (which include most trees and crop species such as wheat, rice, barley, cassava, and potato) have relatively poor WUE, unlike $C_4$ plants (most of the tropical grasses and agricultural species such as maize, sugarcane, and sorghum). Higher $CO_2$ concentration will likely improve water-use efficiency and growth in $C_3$ plants in water-limited environments. $C_4$ and CAM plants (including desert plants such as cacti) are unlikely to be affected directly by changes in $CO_2$ concentration.

The amount of water available to plants over the course of the year affects plant growth and location across soil and climate types. Available soil water (in combination, of course, with other factors) generally controls the growth cycle (beginning and end) and other events such as when to leaf, shed leaves, set buds, and so forth. Water availability and temperature indices and parameters (maxima and minima, heat sums, cold sums) have been used to relate the distribution of vegetation formations to climatic factors (for more details on these plant biogeography models, see Section 2.3.1.4). However, large uncertainties in GCM precipitation projections constrain our ability to project ecosystem responses to changes in climate. Thus, improving climate modeling at the regional scale is a priority in most of Africa, where ecosystem processes are limited by moisture.

#### 2.3.1.3. *Soils, Plant Growth, and Land Degradation*

Many African soils are agriculturally poor, because they are very old, badly leached, and often infertile. Laterites (the oldest soils) are agriculturally unproductive. Laterized red earths are younger and less leached and occur in regions of heavy rainfall, so they are quite agriculturally productive. Nonlaterized red earths, which are found in drier regions (e.g., savannas), are good agricultural soils. Upland red earths are an immature group that occasionally are intensively farmed. In regions of moderate rainfall, the most fertile soils are located in the high veld of southern Africa and parts of west Africa. The black soils—the vertisols—are very fertile but become adhesive during the rainy season and almost rock-like in the drought period. In arid regions, soil humus is very low; moisture often is drawn upward by capillarity and, on evaporation, deposits dissolved minerals in a crust at the surface. In Mediterranean regions, the summer drought, the absence of frost, and the small degree of chemical weathering has led to poorly formed soils.

The ability for soil to support particular natural or agricultural communities is fundamental in any future scenarios of ecosystem development. Soil development is slow and will likely lag climate and vegetation change. In the short term, changes in the soil-water regime and turnover of organic matter and related mineralization or immobilization of nitrogen and other nutrients will have the greatest effect on ecosystem functions. Among the factors that will affect these soil processes, fire and land use probably are the most important. Changes in fire regimes (e.g., frequency, intensity) will directly influence organic-matter processes in the soil and nutrient fluxes—and so will have a significant impact on how soils will function. Land use and land-use history on given sites influence nutrient dynamics and the potential for erosion damage.

Land degradation—defined as "a reduction in the capability of the land to support a particular use" (Blaikie and Brookfield, 1987)—is a major problem in Africa and the whole world. Support by African countries for the Convention on Desertification (United Nations, 1992)—which recognizes that 66% of the continent is desert or dryland, and 73% of the agricultural drylands already are degraded—clearly shows that most African governments are aware of this problem.

Recognized forms of land degradation include soil erosion, salinization, soil contamination, loss of soil organic matter, decline in nutrient levels, acidification, and loss of soil structure. Low rainfall, long dry seasons, recurrent droughts, mobile surface deposits, skeletal soils, and sparse vegetation encourage desertification (Le Houerou, 1989; Dregne, 1983; Kassas, 1995). A combination of climatic variations and human land-management practices can lead to excessive land degradation, eventually leading to desertification. Thus, efforts to reduce vulnerability to climate change must take into account land management and the social and economic factors that drive people's use of the land.

Most studies of soil erosion have looked at soil loss from plot-based measurements and then extrapolated to estimate total soil loss per hectare. Although soil erosion clearly is a major problem in many parts of Africa, simple extrapolations from plots to whole countries and into the future can be misleading. Erosion is a major problem locally, and steps must be taken

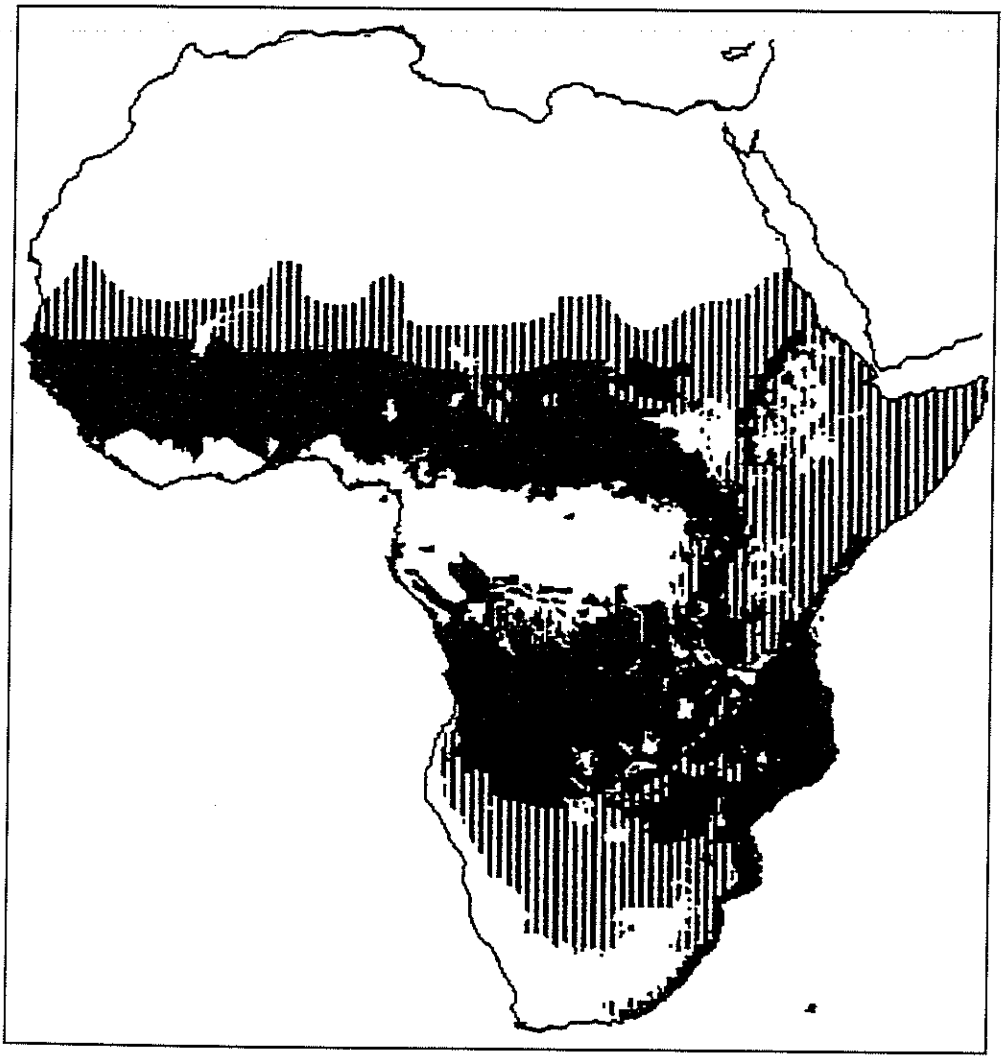


**Figure 2-5**: The distribution of broad-leafed and fine-leafed savannas in Africa. Dark-shaded areas are broad-leafed, nutrient-poor, moist savannas, and striped areas are fine-leafed, nutrient-rich, arid savannas. This map has been derived from White (1983) by reclassifying woodland and wooded grassland map units into one of the two savanna classes according to the dominant tree species.

to combat soil erosion at the farm and catchment levels. Reij *et al.* (1996) argue for participatory approaches to soil and water conservation, rather than large-scale, top-down interventions that encompass technology alone. The social and economic context is critical for success.

### 2.3.1.4. *Forest and Woodland Ecosystems*

Forests in Africa are of great socioeconomic importance as sources of timber, fuel, and many nonwood products, as well as for the protection of water resources. Ecologically, they serve critical roles in water, carbon, and nutrient cycling. The impacts of climate change on forests at the continental scale will be assessed in very broad terms using biome distribution models.

In geological time scales, forest boundaries fluctuated a great deal during the Pleistocene epoch (Sayer *et al.*, 1992); the forests of Africa even now are considerably more extensive than they were during the most recent high-latitude glacial advance about 18,000 years ago. Environmental conditions in tropical Africa at about 18,000 before present (BP) are quite well known, thanks to a large number of pollen and plant microfossil studies (see Hamilton, 1988, for more details). During the severe arid period around 18,000 BP, core areas (centers of biotic diversity) were the main centers of forest survival. Two such principal core areas are located in Cameroon/Gabon and eastern Democratic Republic of Congo (DRC) (formerly Zaire); other, less-diverse core areas are in west Africa and near the east African coast (Sayer *et al.*, 1992). The core areas are not only rich in numbers of species and endemics but also are centers of distribution of disjunct species. Some of these species are unlikely to be able to disperse from core area to core area without continuous forest cover. For example, gorillas are disjunctly distributed across the Zaire basin (Figures 2-6 to 2-8). Although the forests between the two populations seem suitable for the species, some explanation is needed regarding how their ranges became fragmented. A likely explanation for the gorilla and other obligate forest species is that their ranges became fr mented as a result of forest retraction at times of aridity that these species subsequently have been slow to exp their range to include all potentially suitable habitat. Th animal species may not adapt fast enough to rapid change climate.

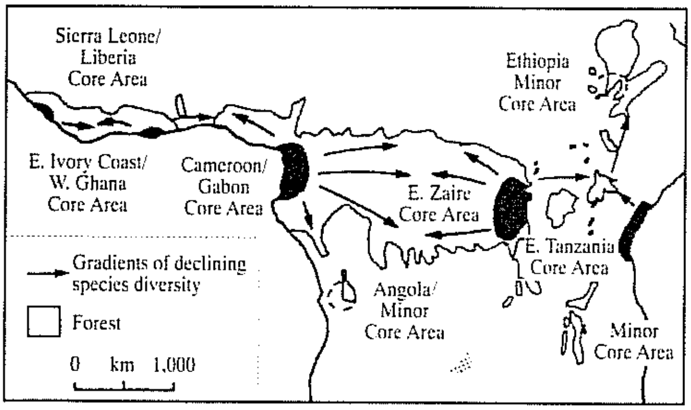


**Figure 2-6**: Distribution of forest, core areas, and gradients of decreasing biotic diversity in tropical Africa. Core areas are believed to approximate sites of forest refugia at the time of the last world glacial maximum (18,000 BP) (Hamilton, 1988).

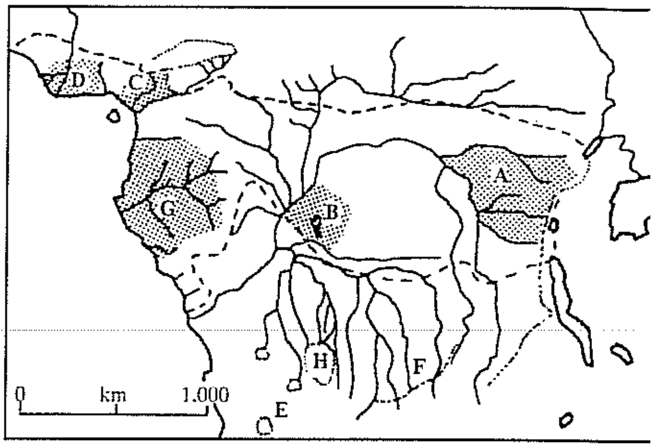


**Figure 2-7**: Forest refugia during arid periods in central Africa: A) Central refuge; D,C,G) Cameroon/Gabon refuge (D, Niger section; C, Cameroon section; G, Gabon or Ogoowe basin section); B) southern Zaire basin refuge; E) north Angola refuge; F) southern scarps of Zaire basin; and H) Lunda Plateau (Kingdon, 1980).

Current vegetation distribution can be studied using bio distribution models. Biome distribution models such MAPSS (Neilson, 1995) and BIOME3 (Haxeltine Prentice, 1996) simulate the distribution of potential glo vegetation based on local vegetation and hydrologi processes and the properties of plants. They simulate the m ture of life forms (such as trees, shrubs, and grasses) that coexist at a site while in competition with each other for li and water. These models simulate the maximum carry capacity, or vegetation density (in the form of leaf area), can be supported at the site under the constraints of energy water. A change in leaf area can be interpreted as a change overall carrying capacity or standing crop of the site, rega less of whether it is potential natural vegetation or under c tivation. This carrying capacity potential is the basis for ap cation of these models to all of Africa to indicate possi shifts in agricultural or vegetation potential.

MAPSS and BIOME3 outputs were generated (see Ann C) using several GCM scenarios, with and without C effects and aerosol emissions. Table 2-1 summari changes in areal coverage for four main biome types Africa (the shrub/woodlands biome was combined w grasslands). The models indicate a net shift from more a biomes (low leaf area index—LAI) to more mesic bio (higher LAI) for the OSU, GFDL, and UKMO scenarios. Ex percentages of change and where this change would occur highly uncertain because the models indicate potential, actual, vegetation.

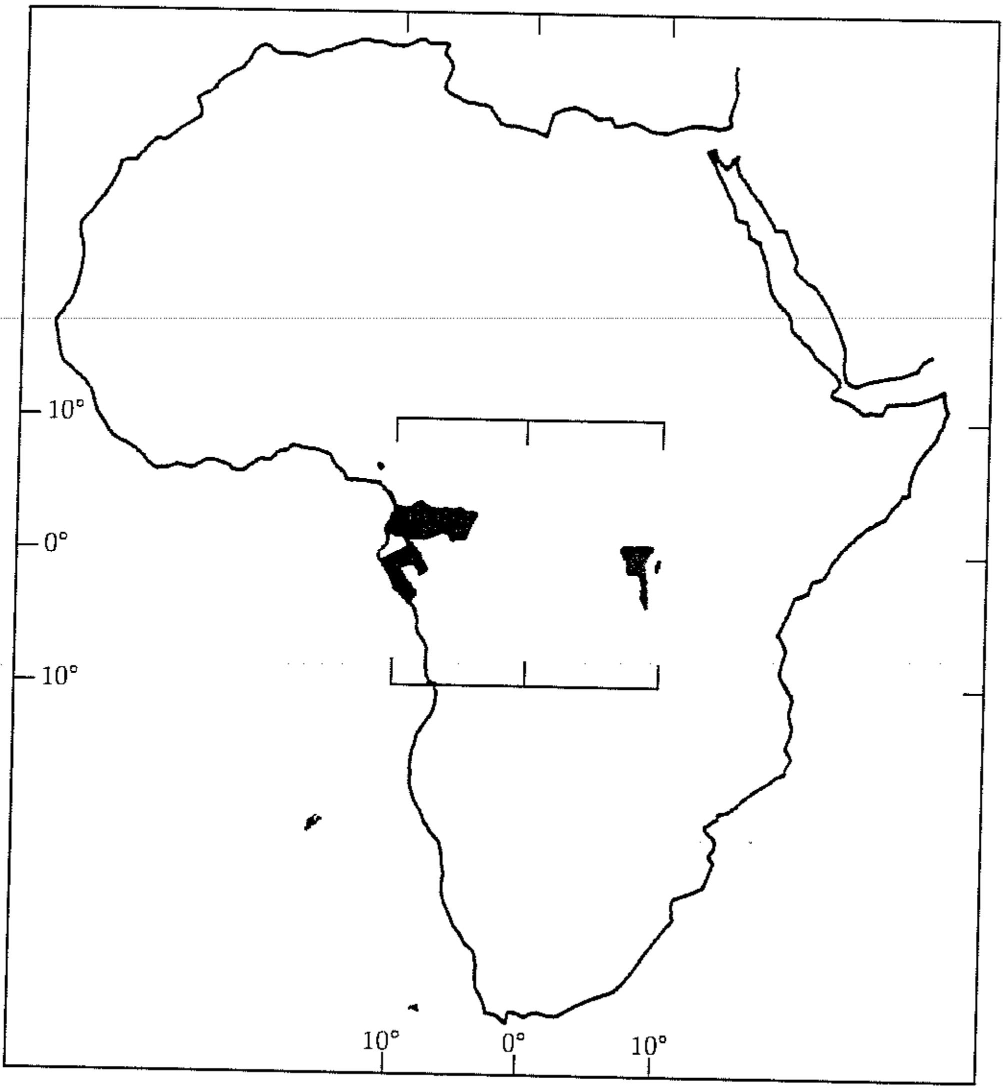


**Figure 2-8**: The distribution of gorillas in Africa (Harcourt *et al.*, 1989).

The biome models are able to capture some overall divisions (e.g., rainforest versus woodland versus arid), but they do not yet capture fine-scale detail for Africa. This limitation is a result of the quality of the climate data used as inputs, coarse soils information, and the nature of the models—which were primarily designed to describe vegetation in temperate climates.

Biome distribution models simulate only static vegetation (i.e., equilibrium vegetation at a future date). Factors that affect vegetation dynamics, such as competition and disturbance (fire, herbivory), are not considered. These factors have not yet been incorporated in global vegetation models (but see Woodward and Steffen, 1996, for plans and developments in this area). An important factor to consider with regard to whether a vegetation type can respond as simulated is migration. Migrating species would require corridors of unmanaged land. The fragmented nature of remaining African vegetation (outside the rainforests) would make vegetation responses to climate change difficult. The destructive aspects of fires also would reduce migration. The dynamics of savannas and woodlands (such as miombo) are strongly linked to fires, so likely changes in fire intensity and frequency will have unknown consequences on vegetation.

Some progress is being made in the development of models of vegetation dynamics that include the effects of fire and herbivory for African vegetation (e.g., Menaut *et al.*, 1991; Van Dalaan and Shugart, 1989; Desanker, 1996). However, these models have to be widely tested and validated before they can be used to evaluate impacts of climate change at the broad scale. Results of biogeochemical modeling in savannas using the CENTURY model of Parton *et al.* (1992) are discussed in Section 2.3.1.5.

*Table 2-1: Changes in areal coverage (in 1,000 km²) of major biome types under current and GCM scenarios using MAPSS (with a direct $CO_2$ effect).*

| **Biome Type**[1] | **Current**[2] | **OSU**[3] | **GFDL**[3] | **UKMO**[3] |
|---|---|---|---|---|
| Tropical broad-leafed forest | 2,986 | 5,752 | 4,798 | 2,909 |
| Savanna/woodland | 8,845 | 8,662 | 9,462 | 11,449 |
| Lumped shrub and grass | 8,713 | 7,534 | 8,083 | 8,025 |
| Arid | 8,814 | 7,497 | 7,146 | 7,200 |

[1] Biome types are defined in the MAPSS model description in Annex C. Minor biome types have been ignored in this table; therefore, column totals will not be the same. Model experiments are $2xCO_2$ equilibrium scenarios and are described in Annex C.

[2] 1961–90 average climate.

[3] All scenarios are $2xCO_2$ equilibrium scenarios.

#### *2.3.1.5. Rangelands*

Rangelands in Africa (i.e., grasslands, savannas, and woodlands, which contain both grasses and woody plants) cover approximately $2.1 \times 10^9$ ha. Africa's livestock population of about 184 million cattle, 3.72 million small ruminants (sheep and goats), and 17 million camels extracts about 80% of its nutrition from these vast rangelands (IPCC 1996, WG II, Table 2-1). In addition, Africa's rangelands support a vibrant tourist industry that, in many countries, is the leading contributor to gross national product (GNP). Because Africa's population has been growing at about 3% annually, the rangelands recently have become an arena for intense human and animal conflict, leading to serious reduction in spatial distribution and diversity of species. This reduction is likely to be exacerbated by projected changes in climate.

From a land-use perspective, there are differences between west Africa and east Africa in the way rangelands are used. In arid and semi-arid areas of west Africa (rainfall 5–600 mm), millet (or another crop) is planted over a unimodal (one peak in rainfall per year) rainy season (3–4 months); then fields remain fallow over the 8- to 9-month dry season. Livestock eat crop residues. Land use is dominated by cultivation, with livestock playing a subsidiary role in the village economy (Ellis and Galvin, 1994). In east Africa, by contrast, areas with higher rainfall (up to 600 mm) are inhabited by pastoral people rather than farmers. The Ngisonyoka of northern Kenya, for example, are pastoral nomads, completely dependent on their livestock for food, livelihood, and life (Galvin, 1992). In dry parts of eastern Africa, cultivation is uncommon and occurs mainly where irrigation is possible or where water can otherwise be sequestered and stored for cropping (Ellis and Galvin, 1994). Rainfall is bimodal (two peaks in rainfall per year) in most east African rangelands, resulting in two plant-growing seasons. This pattern has important implications for natural vegetation and rain-fed agriculture (de Ridder *et al.,* 1982). According to Ellis *et al.* (1987), Turkana pastoralists in northern Kenya say that the best years for livestock production are not necessarily those with the greatest rainfall. Rather, years in which moderate rainfall extends over several months, resulting in a long period of foliage production and livestock milk production, are good years. Thus, the distribution and timing of rainfall will be at least as important as total annual amounts projected under climate change.

Rangelands are noted for high climatic variability and high frequency of drought events. They have a long history of human use. The combination of climatic variability and human land use make rangeland ecosystems more susceptible to rapid degeneration of ecosystem properties (Parton *et al.,* 1996). Because these systems develop under highly variable rainfall regimes, they are conducive to rapid changes in ecosystem structure given modifications in fire and grazing patterns (Archer *et al.,* 1994; Ojima *et al.,* 1994) and altered climate regimes (OIES, 1991).

At the very broad scale, simulations with the biome models (MAPSS and BIOME3) projected increases in the extent of rangelands, mainly as a result of a reduction in the area of a and semi-arid desert resulting from the reduction of droug stress with projected higher rainfall. However, ecosyste process models are more appropriate in analysis of this spec ic ecosystem type. Ojima *et al.* (1996) used the CENTU (Parton *et al.,* 1992) ecosystem process model of plant-s interactions to analyze the impact of climate and atmosphe $CO_2$ changes on grasslands of the world, including 7 of 31 sit in Africa. Ojima *et al.* (1996) looked at the effects of increa ing $CO_2$ and climate, using climate change scenarios based the Canadian Climate Centre (CCC) and GFDL GCMs. Th found that changes in total plant productivity were positive correlated to changes in precipitation and nitrogen mineraliz tion (with nitrogen mineralization the most important facto The response to nitrogen mineralization was consistent wi the general observation that grasslands respond positively addition of nitrogen fertilizer (Rains *et al.,* 1975; Lauenro and Dodd, 1978). Plant responses to $CO_2$ were modified complex ways by moisture and nutrient availabilities; the results generally indicated that $CO_2$ enrichment had a great effect with higher moisture stress. However, nutrient limit tions reduced $CO_2$ responses. Ojima *et al.* (1996) conclude that increased atmospheric $CO_2$ will offset the negative effect of periodic droughts, making grasslands more resilient to nat ural (and human-induced changes in) climate variability. Th strength of this beneficial effect, however, is controlled by th availability of nitrogen and other nutrients, which tend to b limited in many African landscapes.

#### *2.3.1.6. Deserts*

Deserts are an environmental extreme characterized by low rainfall that is highly variable intra-annually and interannually. Desert air is very dry; incoming solar and outgoing terrestrial radiation are intense, with large daily temperature fluctuations; and potential evaporation is high. Many organisms in the deserts already are near their tolerance limits (IPCC, 1996). The Sahara in north Africa and the Namib desert in southwest Africa are classified as the hottest deserts in the world—with average monthly temperatures above 30°C during the warmest months and extremes above 50°C. The diurnal temperature range often is large; winter nights in the Namib Desert sometimes are as cold as 10°C (IPCC 1996, WG II, Section 3.3.1) or lower. Extreme desert systems already experience wide fluctuations in rainfall and are adapted to coping with sequences of extreme conditions. Initial changes associated with climate change are less likely to create conditions significantly outside present ranges of tolerance; desert biota show very specialized adaptations to aridity and heat, such as obtaining their moisture from fog or dew (IPCC 1996, WG II, Section 3.4.2).

#### *2.3.1.7. Mountain Regions*

Mountains usually are characterized by sensitive ecosystems and regions of conflicting interests between economic development and environmental conservation. In Africa, most mid-elevation ranges, plateaus, and high-mountain slopes are under considerable pressure from commercial and subsistence farming activities (Rogers, 1993). Mountain environments are potentially vulnerable to the impacts of global warming. This vulnerability has important ramifications for a wide variety of human uses—such as nature conservation, mountain streams, water management, agriculture, and tourism (IPCC 1996, WG II, Section 5.2).

There is a general picture of continuing ice retreat on the mountains. On Mount Kenya, the Lewis and Gregory glaciers have shown recession since the late 19th century (IPCC 1996, WG II, Box 5-3). Changes in climate (as projected in Greco *et al.*, 1994) could reduce the area and volume of seasonal snow, glacier, and periglacial belts—with a corresponding shift in landscape processes. The retreat of some glaciers on Kilimanjaro and Mt. Kenya would have significant impacts on downstream ecosystems, people, and their livelihoods because of moderation of the seasonal flow regimes of rivers upstream. Further reduction of snow cover and glaciers also could reduce the scenic appeal of African high mountain landscapes for tourists and thus have a negative impact on tourism.

Forest fires would increase in places where summers become warmer and drier. Prolonged periods of summer drought would transform areas already sensitive to fire into regions of sustained fire hazard. Mt. Kenya and mountains on the fringes of the Mediterranean Sea already subject to frequent fire episodes could be affected (IPCC 1996, WG II, Section 5.2.2.3).

### 2.3.1.8. *Adaptation and Vulnerability*

There is potential for spontaneous and assisted adaptation in Africa. Many options will need to involve a combination of efforts to reduce land degradation and foster sustainable management of resources. This section highlights options for forestry and woodlands, rangelands, and wildlife.

A number of adaptive processes designed to prevent further deterioration of forest cover already are being implemented to some degree. Some of these measures involve natural responses when particular tree species develop the ability to make more efficient use of reduced water and nutrients under elevated $CO_2$ levels. Other adaptive measures involve human-assisted action programs (such as tree planting) designed to minimize undesirable impacts. These strategies will include careful monitoring and microassessment of discreet impacts of climate change on particular species. Low-latitude forest adaptation options, especially in west Africa, must include active vegetation and soil management. For example, Gilbert *et al.* (1995) have indicated that silvicultural practices, endangered species habitat management, watershed manipulation, and antidesertification techniques could be applied given current infrastructure in Cameroon and Ghana. These adaptive measures will help reduce climate change impacts on forest watersheds and semiarid woodlands. Smith and Lenhart (1996) have identified enhancement of forest seed banks as an adaptation policy option for maintaining access to a sufficient variety of seeds to allow the original genetic diversity of forests to be rebred. Genetic diversity also provides an assurance that benefits provided by forests are not lost forever (Smith and Lenhart, 1996) and is particularly relevant to the maintenance of the forests in the Sahel and other extremely sensitive regions of Africa where 20 years of recurrent drought have degraded the forests. Mwakifwamba (1997) asserts that adaptation strategies or measures in Tanzania should focus mainly on reducing high deforestation rates, protecting existing forests, and introducing new species or improving existing species.

For rangelands, Milton *et al.* (1994) present a conceptual model of arid rangeland degradation that suggests that degradation proceeds in steps—increasingly difficult and costly to reverse—and discusses adaptation options (see Box 2-4). Assisted management is a lot harder for wildlife in game reserves than for livestock. Monitoring is required to identify populations at risk (from deforestation), as well as reserved areas that are changing their vegetation types in response to climate, leaving some animals in habitat types that are not suitable. Massive fragmentation of previous forests and woodlands makes it difficult for wildlife to migrate along corridors to areas with more water and foliage. Close monitoring would identify groups of wildlife that are in danger, and steps can be taken to move them to suitable habitat.

At the institutional level, mechanisms need to be created (or improved upon) to facilitate the flow of scientific results into the decision-making and policy-making process. Joint planning of projects that would impact cross-boundary catchment areas will become increasingly important if the climate becomes more variable and water more scarce for many regions of Africa.

## 2.3.2. *Hydrology and Water Resources*

Water resources are inextricably linked with climate, so the prospect of global climate change has serious implications for water resources and regional development (Riebsame *et al.*, 1995). Efforts to provide adequate water resources for Africa will confront a number of challenges, including population pressure, problems associated with land use such as erosion/siltation, and possible ecological consequences of land-use change on the hydrological cycle. Climate change will make addressing these problems more complex.

### 2.3.2.1. *Hydrological Systems*

Africa has several surface water bodies spread throughout the continent. Table 2-2 lists the 10 largest surface-water bodies in sub-Saharan Africa, along with basin countries and basin area (after Rangeley *et al.*, 1994). Other smaller water bodies exist within country boundaries. Africa has the greatest number of rivers and water bodies that cross or form international boundaries. The 10 river basins in Table 2-2 (including Lake Chad) have a total drainage area greater than 350,000 km$^2$, and they

### Box 2-4. A Conceptual Model of Arid Rangeland Degradation

Overuse by a narrow suite of domesticated herbivores has led to progressive loss of secondary productivity and diversit in rangelands. Degraded rangelands may not return to their original state, even when they are rested for decades (Westoby *et al.*, 1989; O'Connor, 1991). Milton *et al.* (1994) develop the idea that the probability of reversing grazing-induced change may be inversely related to the amount of disturbance involved in the transition. They develop a stepwise model of rangeland degradation and show how the potential for recovery appears to be related to the function of th affected component. Their study stresses the need to recognize and treat degradation early because management inputs and costs increase for every step in the degradation process. Steps and management options are described below.

Similar models can be constructed for climate effects, to conceptualize potential impacts and points of intervention.

*Steps and management options for arid rangeland degradation.*

Stepwise degradation of arid or semi-arid rangelands. Symptoms describe the state of plant and animal assemblages; management options refer to actions that a manager could take to improve the condition of the range; and management level refers to the system (level of the food chain) on which management should be focused.

| | |
|---|---|
| **Step 0** | |
| Description: | Biomass and composition of vegetation varies with climatic cycles and stochastic events (e.g., droughts, diseases, hail, frost, fire) |
| Symptoms: | Perennial vegetation varies with weather |
| Management Option: | Adaptive management, involving timely manipulations of livestock densities |
| Management Level: | Secondary producers (i.e., grazers and herbivores) |
| **Step 1** | |
| Description: | Herbivory reduces reestablishment of palatable plants, allowing populations of unpalatable species to grow |
| Symptoms: | Demography of plant population changes (age-structural changes) |
| Management Option: | Strict grazing controls |
| Management Level: | Secondary producers |
| **Step 2** | |
| Description: | Plant species that fail to establish are lost, as are their specialized predators and symbionts |
| Symptoms: | Plant and animal losses, reduced capacity to support herbivores |
| Management Option: | Manage vegetation (e.g., add seed, remove plants) |
| Management Level: | Primary producers (i.e., vegetation) |
| **Step 3** | |
| Description: | Biomass and productivity of vegetation fluctuates as ephemerals and weed species benefit from loss of cover from perennial plants |
| Symptoms: | Perennial biomass reduced (short-lived plants and instability increase), resident birds decrease, nomadic bird species |
| Management Option: | Manage soil cover (e.g., mulching, erosion barriers, roughen soil surface) |
| Management Level: | Physical environment (soil) |
| **Step 4** | |
| Description: | Denudation and desertification involve changes in soil function and soil microbe activity |
| Symptoms: | Vegetation cover completely lost, erosion accelerated; soil salinization, aridification |
| Management Option: | Difficult to address; costs of restoration or rehabilitation too high; nonpastoral use of land only economic option |
| Management Level: | Difficult to identify |

*Table 2-2: The 10 largest surface-water bodies in sub-Saharan Africa (Rangeley et al., 1994).*

| Basin | No. of Countries | Basin Area (1,000 km²) | Basin Countries |
|---|---|---|---|
| Congo | 9 | 3,720 | Zaire, Central African Republic, Angola, Congo, Zambia, Tanzania, Cameroon, Burundi, Rwanda |
| Nile | 10 | 3,031 | Sudan, Ethiopia, Egypt, Uganda, Tanzania, Kenya, Zaire, Rwanda, Burundi |
| Niger | 9 | 2,200 | Mali, Nigeria, Niger, Guinea, Cameroon, Burkina Faso, Benin, Cote d'Ivoire, Chad |
| Lake Chad | 6 | 1,910 | Chad, Niger, Central African Republic, Nigeria, Sudan, Cameroon |
| Zambezi | 8 | 1,420 | Zambia, Angola, Zimbabwe, Mozambique, Malawi, Botswana, Tanzania, Namibia |
| Orange | 4 | 950 | South Africa, Namibia, Botswana, Lesotho |
| Okavango | 4 | 529 | Botswana, Angola, Namibia, Zimbabwe |
| Limpopo | 4 | 385 | South Africa, Botswana, Mozambique, Zimbabwe |
| Volta | 6 | 379 | Burkina Faso, Ghana, Togo, Cote d'Ivoire, Benin, Mali |
| Senegal | 4 | 353 | Mali, Mauritania, Senegal, Guinea |

combine to affect 33 sub-Saharan countries and Egypt. Sharma *et al.* (1996) assert that few of the transboundary river basins in the region are effectively jointly managed. Effective management would require treaties, political commitment, institutions, capacity, information, and finance. National interests often override regional objectives. The large number of countries belonging to multiple river and lake basins makes regional cooperation very difficult. Table 2-3 shows dependence on external surface water for selected countries. Coordinated action among African countries will determine whether countries in the region can effectively adapt to changes in the hydrology of African rivers and lakes.

The major effects of climate change on African water systems will be through changes in the hydrological cycle, the balance of temperature, and rainfall. A case study of the impacts of climate change on the Zambezi and Nile River basins follows, based on Riebsame *et al.* (1995). Additional literature on the Zambezi basin includes Calder *et al.* (1996), Pinay (1988), Balek (1977), Conway and Hulme (1993), Vorosmarty and Moore (1991), Vorosmarty *et al.* (1991), and du Toit (1983).

The Nile and Zambezi basins are the second and fourth largest river systems in Africa; key geographic characteristics are depicted in Figure 2-9 and key hydrological characteristics given in Table 2-4. Both the Nile and Zambezi have a low runoff efficiency and a high dryness index, indicating a high sensitivity to climate change. Analysis showed the Nile as very sensitive while the Zambezi was fairly sensitive. Although the severity of the impacts of climate change depended primarily on the magnitude of change, the different hydrological sensitivities of the basins are also important. The Nile and Zambezi are especially sensitive to climate warming: Runoff decreases

*Table 2-3: Dependence on external surface water—selected countries (after Gleick, 1993).*

| Country | %Total Flow Originating Outside Border | Ratio of External Water Supply to Internal Supply[1] |
|---|---|---|
| Egypt | 97 | 32.3 |
| Mauritania | 95 | 17.5 |
| Botswana | 94 | 16.9 |
| The Gambia | 86 | 6.4 |
| Congo | 77 | 3.4 |
| Sudan | 77 | 3.3 |
| Niger | 68 | 2.1 |
| Senegal | 34 | 0.5 |

[1] "External" represents river runoff originating outside national borders; "internal" includes average flows of rivers and aquifers from precipitation within the country.

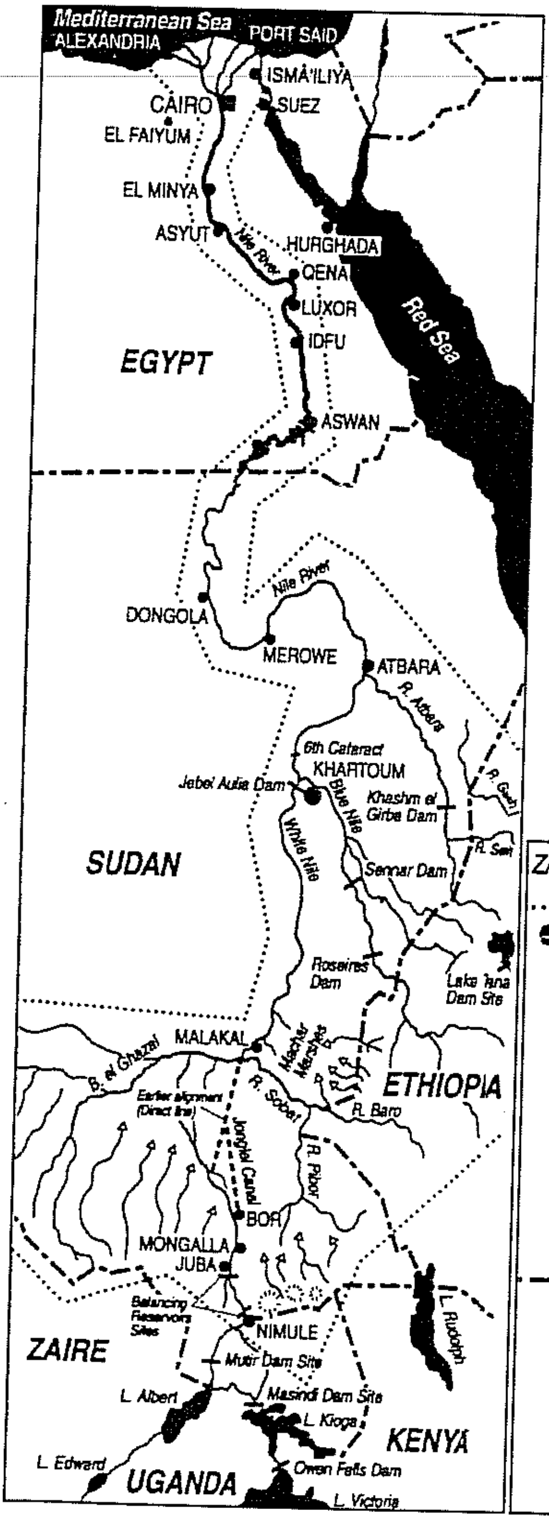
in these basins even when precipitation increases, due to the large hydrological role played by evaporation.

There were striking responses in runoff for the Nile. Riebsame *et al.* (1995) conclude that despite potential adjustments, Nile flows throughout the basin are extremely sensitive to temperature and precipitation changes. GCM scenarios provide widely divergi pictures of possible future river flows, from a 30% increase to 78% decrease. There are formal agreements between Egypt ar Sudan on the allocation of flows from the Nile, now and und any future enhancements. However, any reductions over 20 would exceed the management capability of the agreements an

*Table 2-4: Hydrological characteristics for the Zambezi and Nile River basins (extracted from Riebsame et al., 1995).*

| Parameter | Zambezi | Nile | Blue Nile |
|---|---|---|---|
| Length (km) | 2,600 | 6,500 | 1,000 |
| Area (km$^2$ x 10$^3$) | 1,330 | 2,880 | 313 |
| Flow (m$^3$/sec) | 4,990 | 2,832 | 1,666 |
| Flow (10$^9$ m$^3$/yr) | 157 | 89 | 53 |
| Specific Discharge (l/sec-km$^2$) | 3.8 | 1.0 | 5.3 |
| Runoff (R) (mm) | 118 | 31 | 168 |
| Precipitation (P) (mm) | 990 | 730 | 784 |
| R/P | 0.12 | 0.04 | 0.21 |
| PET/P | 2.50 | 5.50 | 1.80 |

Note: PET = Potential evapotranspiration.



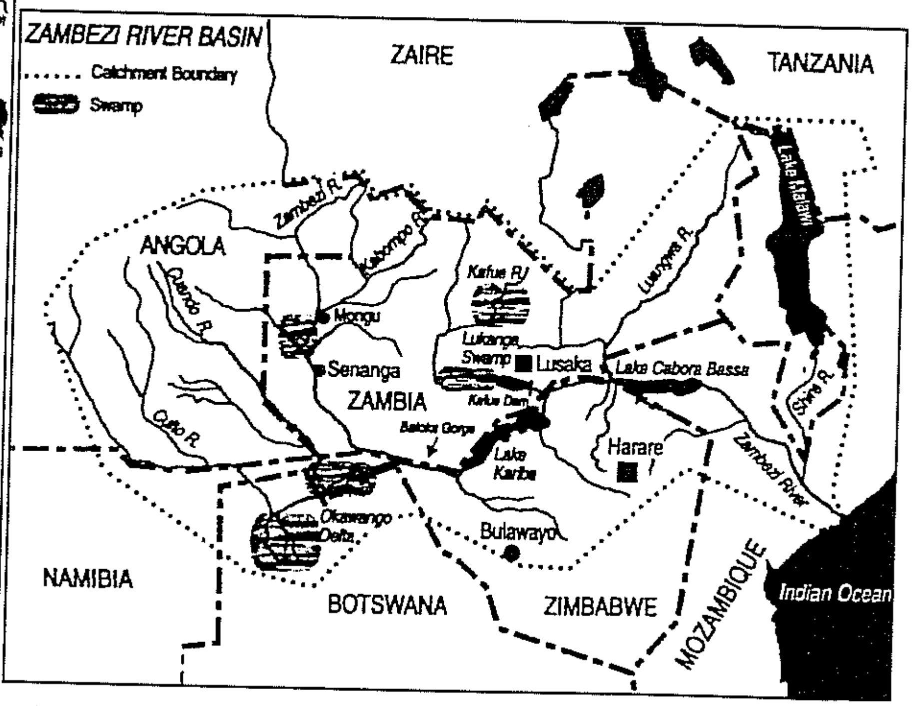


**Figure 2-9**: The Nile and Zambezi River basins. For the Zambesi River basin, climate change impacts were projected for the basin above Lake Kariba with the existing Kariba Dam and with a proposed new dam and reservoir at Batoka Gorge (Riebsame *et al.*, 1995).

would result in major social and economic impacts. Adjustments in response to climate change would either involve changes in water allocation or structural adjustments in the upper and lower basin. The large uncertainty in climate-change projections makes it very hard for basin managers to adopt any response policy. There is need for a regional climate modeling effort over the Nile to help reduce this uncertainty. It remains prudent to make capital investments in decreasing water demand via more efficient irrigation management as a very wise adaptation to climate change.

The seasonal runoff pattern for the Zambezi remained relatively unchanged; the river was sensitive, however, to temporal shifts of the rainy season. There was a net deficit in river flows due to higher surface temperatures, which increase the rate of evapotranspiration. Hydropower production at Kariba decreased slightly under the GISS and GFDL scenarios, while the cooler scenarios of UKMO and GISS led to small increases in power generation. Seasonality of flow had more marked effects on production, a function of storage capacity of the dams in relation to ability to store excess and regulate water flows. Under climate change, there would be less water entering Kariba, and this would likely lead to reduction in fish populations. Adaptation to climate change for the Zambezi basin was suggested to depend on better planning of water projects that consider hydrological inter-relationships of the basin as a whole, crossing many national boundaries. This requirement for countries to look beyond their own needs is a major factor in implementing adaptation options.

The Niger River runs over 4,000 km across west Africa, and its basin covers about one third of the subregion including Guinea, Cote d'Ivoire, Mali, Burkina Faso, Niger, Benin, Nigeria, Cameroon, and Chad. The pressure on this river basin is intense. For example, the Sahelian drought of the 1970s seriously affected hydropower generation from Nigeria's Kaiji Dam on the Niger River during the 1973-77 period. This caused a severe shortfall in power generation to consumers in Nigeria, Mali, Benin, and Chad.

There is some concern that the negative impacts of climate change on water supply could be larger (and the gains smaller) than those reported in current assessments. Many GCMs have not explicitly incorporated the influence of persistent drought in evaluating the impact of global warming. In particular, equilibrium models begin each year with no model memory of groundwater depletion in a preceding year. Yet the successive accumulation of back-to-back drought years often can have devastating effects on groundwater, runoff, reservoir storage, marginal agricultural activities, and water quality (Cline, 1992).

Despite relatively small climatic changes projected for the tropics, tropical lakes also may be quite sensitive to climate change (see Box 2-5). The level of Lake Victoria (in eastern Africa) rose rapidly in the early 1960s following only a few seasons with above-average rainfall and has remained high since (Sene and Pinston, 1994—as cited in IPCC 1996, WG II, Section 10.5.2).

### Box 2-5. African Lakes and Climate Change

African Great Lakes are sensitive to climate variation on time scales of decades to millennia (Kendall, 1969; Livingstone, 1975; Haberyan and Hecky, 1987). Lake Victoria (the world's second-largest freshwater lake by area), Lake Tanganyika (the world's second-deepest lake), and Lake Malawi were closed basins for extended periods in the Pleistocene and Holocene epochs (Owen *et al.*, 1990). Lakes Malawi and Tanganyika were hundreds of meters below their current levels; Victoria dried out completely. Today these lakes are in delicate hydrological balance and are nearly closed. Only 6% of the water input to Tanganyika leaves at its riverine outflow (which was totally blocked when the lake was explored by Europeans) (Bootsma and Hecky, 1993).

Higher temperatures would increase evaporative losses, especially if rainfall also declined. Minor declines in mean annual rainfall (10–20%) for extended periods would lead to the closure of these basins even if temperatures were unchanged (Bootsma and Hecky, 1993). Tropical temperatures are increasing; temperatures in the 1980s were 0.5°C warmer than a century earlier and 0.3°C warmer than during the period 1951–1980. Concurrently, Lake Victoria's epilimnion was warmer by 0.5°C in the early 1990s than in the 1960s (Hecky *et al.*, 1994). Although current climate scenarios project only small increases in tropical temperatures, small changes in temperature and water balance can dramatically alter water levels, as well as mixing regimes and productivity.

Recent temperature and rainfall data and GCM simulations indicate increasing aridity in the tropics (Rind, 1995). Increases of 1–2°C in air temperatures could substantially increase the stability of stratification in permanently stratified Tanganyika and Malawi. Their deep waters are continuously warm, but the <1°C difference between surface and deep water in warm seasons maintains a density difference that prevents full circulation. Lake Tanganyika's deep water has been characterized as a "relict" hypolimnion that formed under a cooler climate within the past 1,000 years (Hecky *et al.*, 1994). Since then, warming has created a barrier to vertical circulation. Additional warming could strengthen this barrier and reduce the mixing of deep, nutrient-rich hypolimnetic water and nutrient-depleted surface layers; that mixing sustains one of the most productive freshwater fisheries in the world (Hecky *et al.*, 1981).

Source: IPCC 1996, WG II, Box 10-1.

### 2.3.2.2. *Water Supply*

Water supply undoubtedly is a most important resource for Africa's social, economic, and environmental well-being. Currently, about two-thirds of the rural population and one-quarter of the urban population are without safe drinking water, and even higher proportions lack proper sanitation. Climate change will likely make the situation more adverse. The greatest impact will continue to be felt by the poor, who have the most limited access to water resources. This section focuses mainly on sub-Saharan Africa (SSA).

Availability of water in SSA is highly variable. Only the humid tropical zones in central and west Africa have abundant water. Availability of water varies considerably within countries, too, influenced by physical characteristics and seasonal patterns of rainfall. According to Sharma *et al.* (1996), eight countries were suffering from water stress or scarcity in 1990; this situation is getting worse as a consequence of rapid population growth, expanding urbanization, and increased economic development. By 2000, about 300 million Africans risk living in a water-scarce environment. Moreover, by 2025, the number of countries experiencing water stress will rise to 18—affecting 600 million people (World Bank, 1995b). Figure 2-10 shows how countries will shift from water surplus to water scarcity as a result of population changes alone between 1990 and 2025, using a per capita water-scarcity limit of 1,000 m$^3$/yr. The scarcity statistics also can be associated with challenges to international water resources: Eight river basins already face water stress, and four face scarcity (Figure 2-11); Figure 2-12 illustrates water availability in the year 2025 (taking account of population increase alone) (Sharma *et al.*, 1996).

During the 1980s and 1990s, drought affected urban areas a industry very severely. Most water-dependent industries southern Africa were forced to reduce their activities af water reservoirs fell to critical levels. Beverage compani which use a lot of water to wash bottles, had to change to nc returnable aluminum cans (which require less wate Botswana's construction and textile industries had to retren workers after operations were scaled down because of a seve shortage of water. Similar problems hit Bulawayo, the heart Zimbabwe's industrial sector; companies were almost forced pull out and relocate elsewhere because of a lack of water, a half of the small businesses crumbled. In South Afric Swaziland, and Zimbabwe, sugarcane industries almost grou to a halt because there was no water for irrigation. Pow rationing in Kenya in 1996–97 as a consequence of droug severely disrupted the country's manufacturing and enginee ing industries (UNEP, 1997).

Unfortunately, there are few assessments of how clima change or responses to it could affect local wetland biodivers ty. The climate change scenarios of Greco *et al.* (1994) proje that there could be less water in most of the large rivers in tl Sahel over the next 30–60 years, with the possible exception ( the major rivers flowing into Lake Chad. This shift woul mean less available water in the large wetlands along thes rivers, unless there are changes to the management of outflo from dams. Changes to the hydrology of smaller wetlands wi depend not only on climate change but also on whether the are supplied with surface water or groundwater, as well as th extent of cropping in their catchment areas. The loss of sma wetlands may lead to a significant risk of extinction for loca populations of turtles and small birds (Gibbs, 1993), althoug

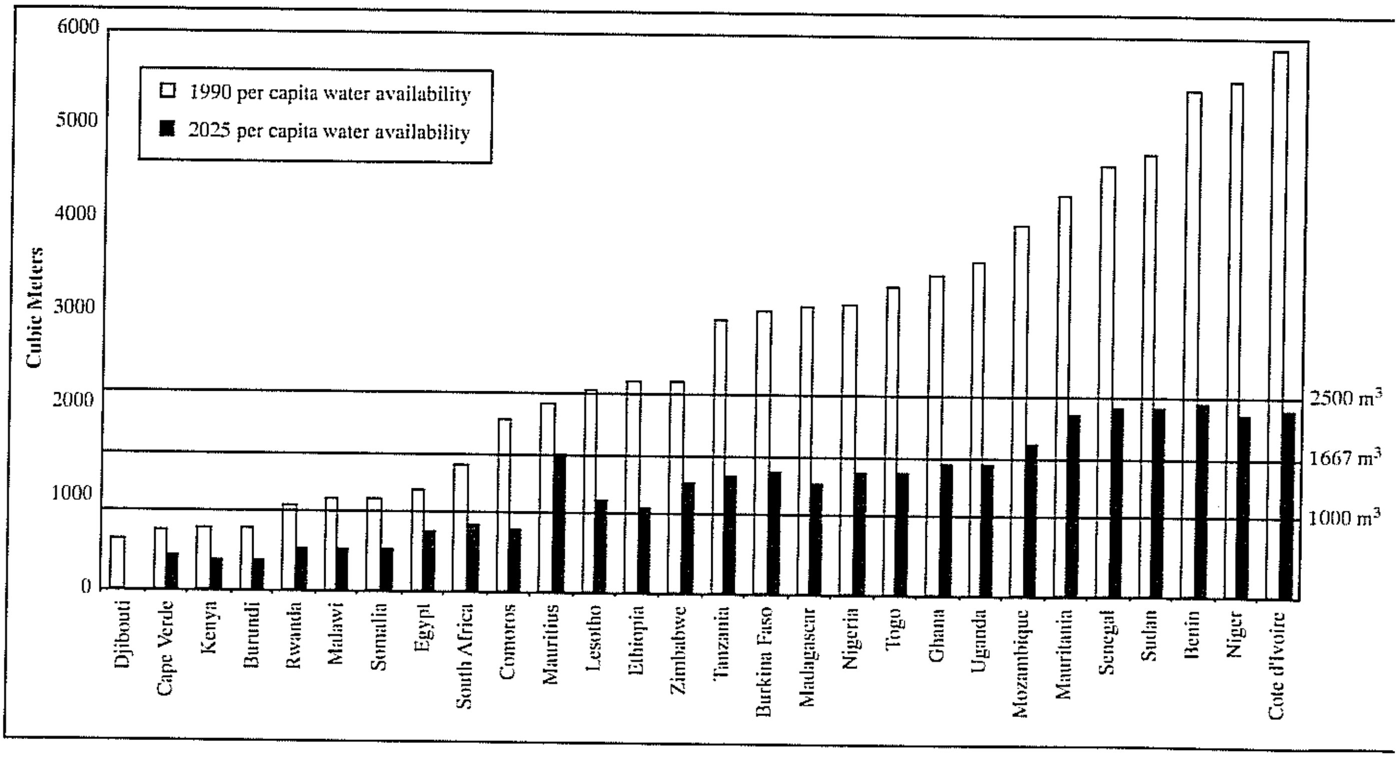


**Figure 2-10**: Water scarcity and people in Africa (Sharma *et al.*, 1996).

taxa that are easily transported as adults, eggs, cysts, larvae, and so forth would be subjected to less risk (Magadza, 1991). If wetlands in the eastern Sahel become drier, relatively mobile birds that are dependent on wetland habitat could move into wetlands further east (i.e., in Niger, northern Nigeria, northern Cameroon, Chad).

### 2.3.2.3. *Adaptation and Vulnerability*

Climate change will have various effects on water resources and water management in Africa. The large variability in projected climate scenarios over Africa's most vulnerable river basin systems (such as the Nile) makes any policy reformulation in anticipation of climate change difficult. However, improved efficiency in irrigation systems and water use are strongly recommended modes of action because they will benefit the region regardless of the degree and direction of climate change. Detailed studies of the river basins are essential to provide adequate information for planning and negotiation purposes in this area that will continue to generate tension across many borders.

Sharma *et al.* (1996) have evaluated the sub-Saharan African countries with respect to their degree of national commitment and planning to address water problems in general and have developed a list of country performance indicators (Table 2-5). Columns 4–7 describe the enabling environment; columns 1 and 2 are poverty indicators; and columns 1, 2, and 3 are risk indicators, where problems will call for either more water or more efficient management of existing stocks. The following points are critical:

- The extent of political stability, ownership of development efforts, and commitment to sustainable water resources management in each country
- The extent to which an enabling environment exists—consisting of transparent and accountable governance in the water sector, clear legislation and policy, strategies and investment programs, stakeholder participation, and the capacity for water resources management at all levels
- The extent to which information and knowledge exists to gauge water availability and quality, consumer demand, and sectoral needs (e.g., sanitation coverage, irrigation, hydropower).

Knowledge also is needed about multiple cross-sectoral linkages relating to a nation's water development (competing demands from agriculture, industry, and municipalities; reliance upon international waters). Depending on how a country fares with regard to the three critical points above, the types of efforts and interventions required by funding agencies and nations will vary. Countries that fare poorly in this analysis will be most vulnerable to climate changes because they will have less capacity to adapt.

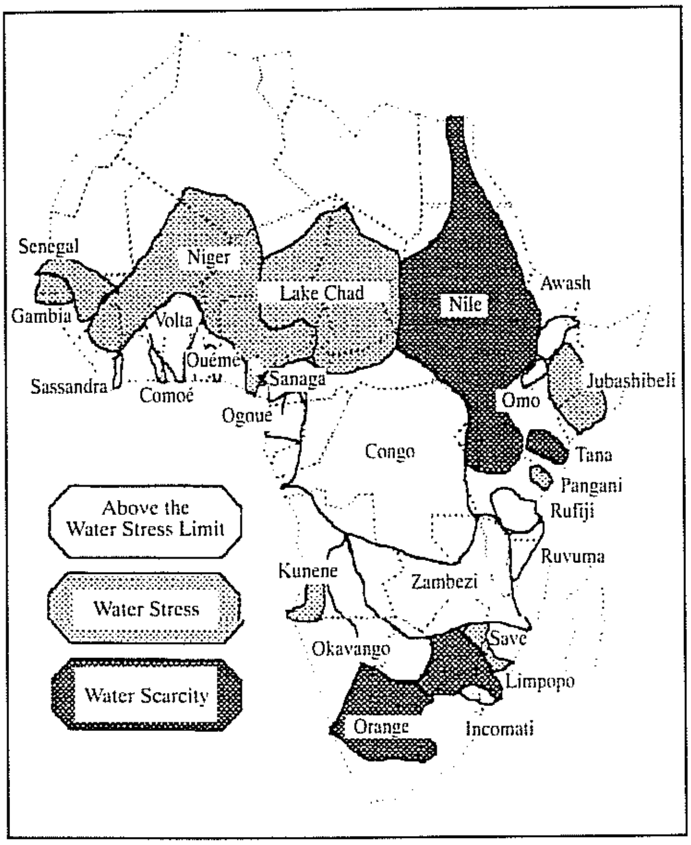


**Figure 2-11**: Water availability at river-basin level (1995) (Sharma *et al.*, 1996).

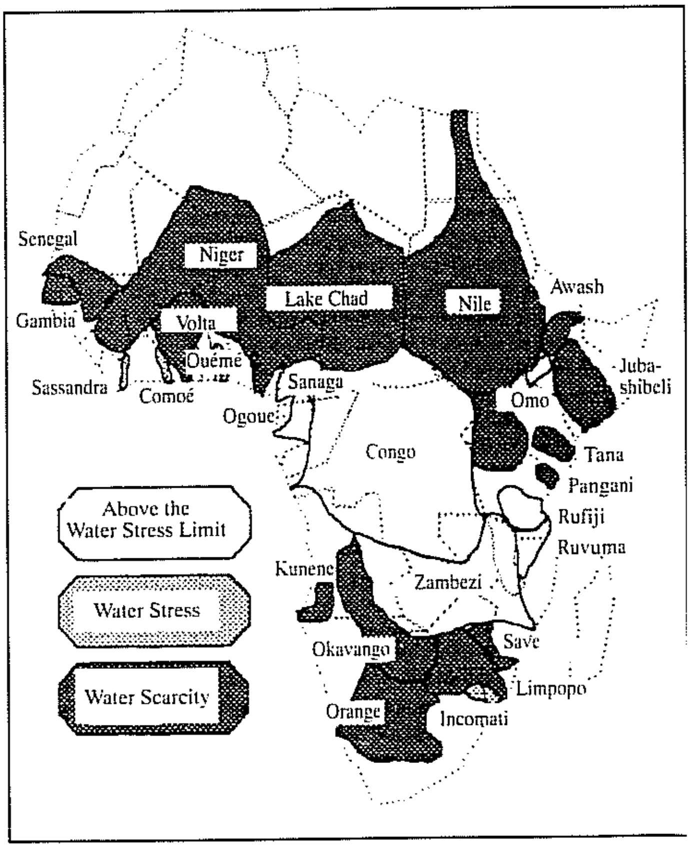


**Figure 2-12**: Water availability at river-basin level (2025) for projected population levels (Sharma *et al.*, 1996).

*Table 2-5: Sub-Saharan Africa: Country indicators for water resources (after Sharma et al., 1996).*

| | (1) % Population with Safe Drinking Water | (2) % Population with Sanitation | (3) Irrigated Area as % of Potential | (4) Governance Environment | (5) Capacity for Resource Management | (6) Status of Water Legislation | (7) Status of Water Plan Policy |
|---|---|---|---|---|---|---|---|
| **Southern Africa** | | | | | | | |
| Angola | Low | Low | Low | Low | Low | Available | Nonavailable |
| Botswana | High | High | Low | High | High | Available | Available |
| Lesotho | Medium | Low | Low | Medium | High | Available | Available |
| Malawi | Medium | High | Low | High | Medium | Available | Available |
| Mozambique | Low | Low | Low | Low | | Available | Nonavailable |
| Namibia | | Low | | High | | Available | Available |
| South Africa | | | | High | Medium | Available | Available |
| Swaziland | Low | Medium | High | High | | Available | Nonavailable |
| Zambia | Medium | Medium | Low | Medium | | Available | Partial |
| Zimbabwe | Medium | Low | Medium | High | High | Available | Available |
| **Eastern Africa** | | | | | | | |
| Djibouti | Medium | Medium | | Low | Low | | |
| Eritrea | | | | Medium | | | |
| Ethiopia | Low | Low | Low | Medium | Medium | Available | Available |
| Kenya | Medium | Medium | Low | Low | Medium | Available | Available |
| Somalia | Low | Low | High | Low | Low | | |
| Sudan | Medium | Low | Medium | Low | Low | | |
| Tanzania | Medium | High | Low | Medium | Low | Available | Available |
| Uganda | Low | Low | Low | Medium | | Nonavailable | Available |
| **Central Africa** | | | | | | | |
| Burundi | Low | Medium | High | Low | Low | | |
| Cameroon | Medium | Medium | Low | Low | Low | Available | Nonavailable |
| Central African Republic | Low | Medium | Low | Low | Low | Available | Nonavailable |
| Chad | Low | | Low | Medium | Low | | |
| Comoros | High | | | Low | | | |
| Congo | Low | Low | Low | Medium | Low | | |
| Equitorial Guinea | Medium | Medium | | Low | Low | | |
| Gabon | High | | Low | Medium | Medium | Available | Nonavailable |
| Madagascar | Low | Low | High | Medium | Low | | |
| Mauritius | High | High | | High | Medium | | |
| Rwanda | Medium | Medium | Medium | Low | Low | | |
| Seychelles | High | | | High | | | |
| Zaire | Medium | Low | Low | Low | Low | | |
| **West-Central Africa** | | | | | | | |
| Benin | Medium | Low | Low | Medium | Medium | Available | Nonavailable |
| Burkina Faso | High | Low | Low | High | Medium | Available | Nonavailable |
| Cote d'Ivoire | High | High | Medium | Medium | Medium | Partial | Partial |
| Ghana | Medium | Low | Low | Medium | Medium | Available | Nonavailable |
| Niger | Medium | Low | Medium | Medium | | Nonavailable | Nonavailable |
| Nigeria | Medium | Low | Medium | Low | Low | Nonavailable | Nonavailable |
| Togo | Medium | Low | Low | Low | | | |
| **Western Africa** | | | | | | | |
| Cape Verde | Medium | Low | | Medium | | Available | Available |
| The Gambia | Medium | Medium | Medium | Medium | Low | Available | Available |
| Guinea | Low | Medium | Medium | Low | Low | Nonavailable | Nonavailable |
| Guinea-Bissau | Low | Low | | Low | | Available | Nonavailable |
| Liberia | Medium | Low | | Medium | Low | | |
| Mali | Low | Low | Medium | Low | | | |
| Mauritania | Medium | Low | Medium | Medium | | | |
| Sao Tome and Principe | Medium | Low | | Medium | Low | | |
| Senegal | Medium | Medium | Medium | Medium | | Partial | Partial |
| Sierra Leone | Low | Low | Medium | Low | Low | | |

Notes: Blank boxes indicate no data available. Columns 1 and 2: Low = 0–33%, Medium = 34–66%, High = 67–100%. Column 3: Low = 0–29%, Medium = 30–60%, High = 61–100%. Column 4 based on political and social stability. Column 5 based on efficiency of domestic resource mobilization and allocation. In Columns 6 and 7, "Partial" indicates draft bill/policy or obsolete laws.

### *2.3.3. Agriculture and Food Security*

#### *2.3.3.1. Socioeconomic Vulnerability*

Many indicators of human development highlight Africa's relative poverty and vulnerability (Table 2-6). With smaller holdings and little investment in agriculture, household production faces difficulties in meeting subsistence requirements or developing specialized export crops. Household expenditures on food are high—more than half of the annual budget, on average. Africa receives the largest amount of food aid of any continent. Low rates of female literacy and high rates of infant mortality are indicative of populations that have low status and inadequate infrastructure for education and health—two essential requirements for vigorous rural development. The high numbers of refugees highlight potential economic and political instability. Vulnerable populations include smallholder agriculturists with inadequate resources, pastoralists, rural landless laborers, and the urban poor. Rural populations are directly affected by climatic variations. Reduced food supplies and high prices immediately affect landless laborers who have little savings. The effect on agriculturists and pastoralists depends on how much surplus they produce and the relative terms of trade (e.g., between food and livestock). A dramatic increase in urban poverty has been noted in the past decade—one consequence of stagnant rural development and high population pressures. The urban poor are indirectly affected by climate change through changes in prices and regional investment.

#### *2.3.3.2. Food and Fiber Production*

Agriculture constitutes a large share of African economies, with a mixture of subsistence and commercial production. Forestry is an important complement to agriculture in many rural areas, but managed forests are less significant. Fisheries are important in coastal areas and islands but a small component of the African economy as a whole. African agriculture is sensitive to present climatic variations. The effects of climate change are uncertain, but adverse impacts are likely in many regions. The future of African agriculture and food security depends on the outcome of climate change in Africa, indigenous responses to global change, development efforts in the next few decades, and global patterns of commodity production and demand (which also are affected by climate change and policy responses to global change).

##### *2.3.3.2.1. Present agriculture*

African economies are highly dependent on agriculture: Arable land and permanent pasture occupy one-third of the land area of Africa. Agriculture constitutes approximately 30% of GDP (see Table 2-7 and Annex D). Almost three-fourths of the African population resides in rural areas, and almost all of the rural labor force is engaged in agriculture (including livestock, forestry, and fisheries). However, much of the land is of poor quality; less than 10% of Africa is actively cultivated. Annual

*Table 2-6: Regional vulnerability to food crises in Africa.*

| | Expenditure on Food (% of consumption) | Food Aid (cereals) (kg per capita) | Refugees | Female Literacy (adult) (%) | Infant Mortality (per 1000) |
|---|---|---|---|---|---|
| **African Region**[1] | | | | | |
| Northern | 42 | 18 | 221,450 | 45 | 59 |
| Sudano-Sahelian | 42 | 13 | 974,800 | 17 | 119 |
| Gulf of Guinea | 39 | 6 | 819,750 | 28 | 109 |
| Central | 39 | 3 | 480,500 | 41 | 97 |
| Eastern | 37 | 4 | 1,408,150 | 43 | 102 |
| Indian Ocean | 57 | 12 | 0 | 73 | 66 |
| Southern | 57 | 15 | 1,793,800 | 53 | 85 |
| *Total* | *57* | *10* | *5,698,450* | *35* | *97* |
| **Comparison Country** | | | | | |
| Bangladesh | 59 | 12 | 245,300 | 22 | 108 |
| Thailand | 30 | 2 | 255,000 | 90 | 26 |
| Mexico | 35 | 3 | 47,300 | 85 | 35 |
| Greece | 30 | -1 | 1,900 | 89 | 8 |
| United Kingdom | 12 | -3 | 24,600 | X | 7 |

[1] **Northern**: Algeria, Egypt, Libya, Morocco, Tunisia; **Sudano-Sahelian**: Burkina Faso, Cape Verde, Chad, Djibouti, Eritrea, The Gambia, Mali, Mauritania, Niger, Senegal, Somalia, Sudan; **Gulf of Guinea**: Benin, Cote d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone, Togo; **Central**: Angola, Cameroon, Central African Republic, Congo, Equatorial Guinea, Gabon, Sao Tome and Principe, Zaire; **Eastern**: Burundi, Ethiopia, Kenya, Rwanda, Tanzania, Uganda; **Indian Ocean**: Comoros, Madagascar, Mauritius, Seychelles; **Southern**: Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe.
Source: WRI, 1994.

food production over the past few decades has grown by 2.8% per year for cereals, 2.9% for legumes, and 4.0% for roots and tubers, although the total cultivated area has grown by only 0.6%. Although population densities are relatively low compared with global averages, some rural areas are very densely populated, and population growth rates have yet to reach stability levels.

Throughout Africa, the staple crops are cereals—maize in particular. Millet and sorghum are widely grown as well; wheat and teff are common in some regions. Almost all agriculture is rain-fed, although irrigation is important in some regions. The absence of irrigation (less than 10% of the cultivated area is irrigated) increases the sensitivity of crop yields to clim variations. Cash crops are important in every country but v in their distribution and profitability. Coffee, tea, groundn cocoa, tobacco, and palm oil are grown as cash crops. Ot significant crops (at least in terms of household consumpti include cassava, yams, legumes, and horticultural crops. Ag pastoralism and extensive nomadic pastoralism are common semi-arid regions. Relying on grass and browse, pastoralism particularly sensitive to long periods of drought when grazi resources are depleted by livestock and not renewed.

The regions of Africa have distinct characteristics. North Afri and the Indian Ocean islands rely on irrigated agriculture.

*Table 2-7: Regional agriculture in Africa.*

| Region[1] | Population Density (pop/km²) | Population Growth (%) | Crop Land (% of total) | Irrigated Land (% of total) | Average Yield of Cereals (kg/ha) | Fertilizer Use (kg/yr) | Food Prod. Inde (1970=100) |
|---|---|---|---|---|---|---|---|
| ***Resources*** | | | | | | | |
| Northern | 226 | 2.25 | 5 | 27 | 1,973 | 94 | 115 |
| Sudano-Sahelian | 106 | 2.72 | 4 | 7 | 727 | 5 | 90 |
| Gulf of Guinea | 891 | 2.83 | 21 | 2 | 892 | 6 | 100 |
| Central | 145 | 2.70 | 4 | 1 | 923 | 2 | 87 |
| Eastern | 541 | 2.88 | 10 | 2 | 1,363 | 12 | 92 |
| Indian Ocean | 262 | 1.96 | 5 | 23 | 1,988 | 140 | 98 |
| Southern | 208 | 2.56 | 6 | 7 | 929 | 27 | 76 |
| *Total* | *253* | *2.65* | *6* | *8* | *1,098* | *25* | *92* |
| Bangladesh | 9,853 | 2.18 | 72 | 31 | 2,572 | 101 | 96 |
| Thailand | 1141 | 0.92 | 45 | 19 | 2,052 | 39 | 109 |
| Mexico | 491 | 1.55 | 13 | 21 | 2,430 | 69 | 100 |
| Greece | 795 | 0.07 | 30 | 31 | 3,700 | 172 | 101 |
| United Kingdom | 2,404 | 0.19 | 28 | 2 | 6,332 | 350 | 112 |

| | GNP per capita ($) | GDP in Agriculture (%) | GDP Growth Rate (%/yr) | Public Agricultural Investment ($) |
|---|---|---|---|---|
| ***Investment*** | | | | |
| Northern | 1,285 | 17 | 3.60 | 25 |
| Sudano-Sahelian | 860 | 34 | 2.36 | 7 |
| Gulf of Guinea | 760 | 39 | 1.87 | 15 |
| Central | 760 | 22 | 2.15 | 5 |
| Eastern | 593 | 47 | 3.05 | 13 |
| Indian Ocean | 280 | 22 | 3.85 | 6 |
| Southern | 333 | 21 | 3.38 | 7 |
| *Total* | *355* | *30* | *2.75* | *11* |
| Bangladesh | 205 | 37 | 4.20 | 68 |
| Thailand | 1,697 | 13 | 7.80 | 78 |
| Mexico | 2,971 | 8 | 1.50 | 129 |
| Greece | 6,530 | 17 | 1.60 | 25 |
| United Kingdom | 33,850 | 2 | 2.80 | 347 |

[1] Regions are as in Table 2-6.

Source: WRI, 1994.

west Africa, the gradient of climates from the Sahara to the humid coast determines the potential for agriculture. Subsistence agriculture and pastoralism dominate the Sudan and Sahelian regions; plantation agriculture is found along the Guinea coast. The highlands of east Africa are well known for productive agriculture that takes advantage of the two rainy seasons. The lowlands, however, are subject to erratic rainfall and poor soils. Coffee and tea are major cash crops in the highlands. The humid and sub-humid zones of central Africa, where drought is seldom a problem, are conducive to roots and tubers.

Most rural households engage in subsistence agriculture, although large commercial estates are found throughout Africa. Moreover, regionally diverse values, cultures, and practices in agriculture make for a truly unique region. In many African cultures, identity and the measure of personal wealth and value are determined by the amount of land one owns, the number of cattle in one's herd, or the amount of food produced for the community, rather than monetary wealth. These nuances make African agriculture a particularly important sector within the climate change debate.

Prolonged drought—lasting a season or longer over a widespread area—is the most serious climatic hazard affecting African agriculture, water supplies, and ecosystems. If droughts become more common, widespread, and persistent, many subhumid and semi-arid regions will have difficulty sustaining viable agricultural systems. Drought-prone environments already have been settled and land converted from extensive grazing and long-fallow cultivation to permanent cropping. Box 2-6 reviews the frequency of drought in Africa and its impacts.

#### 2.3.3.2.2. *Impacts of climate change*

The effects of climatic variations on African agriculture have been well established through decades of field experiments, statistical analyses of observed yields, and monitoring of agricultural production. The most important climatic element is precipitation, particularly seasonal drought and the length of the growing season. The distribution of rainfall within the growing season also may affect yields. Local flooding and storms are minor problems. Low temperatures and radiation limit production in some high-elevation regions; frost is a hazard in South Africa. High temperatures can affect yields and yield quality in semi-arid and arid regions, although water is more important. Sea-level rise and coastal erosion will affect groundwater, irrigated agriculture, and low-lying coastal land in some areas.

The direct effects of $CO_2$ enrichment on plants tend to increase yields and reduce water use. Increased $CO_2$ concentrations increase the rate of photosynthesis and increase water-use efficiency (the efficiency with which plants use water to produce a unit of biomass or yield). The direct effects are strongest for plants with $C_3$ pathways, such as wheat, compared with $C_4$ plants like maize, sorghum, millet, and sugarcane—which are staples for much of sub-Saharan Africa. $CO_2$ enrichment also affects weeds, many of which are $C_4$ plants (Ringius *et al.*, 1996). According to the IPCC Second Assessment Report, the effect of a doubling in $CO_2$ concentrations (from the present) varies from a 10% increase to almost a 300% increase in biomass; WUE may increase by up to 50% (or more) (IPCC, 1996). Thus, the beneficial effects of increased concentrations of $CO_2$ are likely to offset some of the effects of decreased precipitation. However, the effect of $CO_2$ on crops in Africa—where nutrients often are a limiting factor and leaf temperatures are high—remains highly uncertain.

Unfortunately, regional projections of precipitation change diverge quite strongly in Africa. For example, scenarios of summer precipitation in the Sahel show a range of ±20% for nine atmosphere-ocean GCMs reported in Annex B. However, present trends in precipitation in Africa show a decrease in some regions. Recent transient scenarios report lower temperature changes, globally as well as for Africa. Thus, for agriculture, there is little confidence in present scenarios for precipitation—the most important aspect of climate change for African agriculture. However, a combination of the potential effects of increased $CO_2$ concentrations and lower temperatures (at time of doubling) using transient scenarios suggests that the impacts of these scenarios may be less severe than those of earlier equilibrium GCM model experiments. Nevertheless, even a small decrease in precipitation can be significant. Furthermore, few scenarios of drought risk and the distribution of rainfall within the growing season have been developed.

Although African agriculture clearly is sensitive to climatic variations, perhaps equally important is the gap between present and potential agricultural yields in Africa. For example, a serious impact of climate change might be a decrease of 20% in maize yields. Yet present yields among smallholders often are only half (or even one-tenth) of potential yields. The evaluation of potential impacts of climate change should not mask the enormous potential for more-productive agricultural systems in Africa (see Section 2.3.3.2.3).

At the national level, Figure 2-13 shows the variability in national maize yields for selected countries (Hulme, 1996a). The effects of the 1984–85 and 1991–92 droughts are clear (see Box 2-6). The coefficient of variation for annual maize yields varies from about 10% in central Africa to almost 50% in drier countries such as Botswana and Swaziland. A significant component of the variability is likely to be related to rainfall, although prices and market policies are influential. The role of precipitation in agricultural productivity was demonstrated dramatically in the Sahel and eastern and southern Africa during the drought period 1970–95 (Buckland, 1992). Water scarcity revealed widespread dependence on rain-fed agriculture and the lack of infrastructural development for supplemental irrigation and water resources. For example, Zimbabwe in 1991 and 1992 imported 800,000 tons of maize, 250,000 tons of wheat, and 200,000 tons of refined and semirefined sugar to make up the shortfall associated with reduced agricultural production as a result of rainfall shortages (Makarau, 1992). Studies of the role of climatic variability in African food security have a long tradition. At the local level, agroclimatic studies such as Akong'a *et al.* (1988), Downing *et al.* (1990), Mortimore (1989), and Sivakumar (1991, 1993) considered the effects of climatic variability on agriculture, with an emphasis on coping with drought. Back-to-back drought episodes in sub-humid and semi-arid zones led to the failure of crop production and dependency on other sources of income to buy food, or on famine relief.

National crop modeling studies that specifically address climate change now have been carried out for many countries for a variety of purposes (see Sivakumar, 1991, 1993; Eid, 1994; Muchena, 1994; Fischer and van Velthuizen, 1996; Makadho, 1996; Matarira *et al.*, 1996; Sivakumar *et al.*, 1996; USCSP, 1996). Recent studies sponsored by the United Nations Environment Programme (UNEP), the Global Environment Facility (GEF), the USCSP, and others are to be published soon. A few regional studies have been conducted (e.g., Hulme

### Box 2-6. African Drought: Episodes and Impacts

Extensive droughts have afflicted Africa, with serious episodes since independence in 1965–1966, 1972–1974, 1981–1984, 1986–1987, 1991–1992, and 1994–1995 (WMO, 1995; Usher, 1997). The causes of African drought are numerous and vary among regions, seasons, and years. Local droughts occur every year; continental crises appear to occur once (or more recently twice) every decade. Major droughts tend to be connected to ENSO anomalies. It seems prudent to expect drought in Africa to continue to be a major climatic hazard.

The potential effect of climate change on drought in Africa is uncertain. At a local level, increased temperatures are likely to lead to increased moisture demand. The balance between rainfall and higher evapotranspiration implies more frequent water scarcity. However, a great deal depends on vegetation response to higher $CO_2$ concentrations and the timing of rainfall. The combination of higher evapotranspiration and even a small decrease in precipitation could lead to significantly greater drought risks. An increase in precipitation variability would compound temperature effects. For example, Hulme (1996b) reports that interannual variability increases on the order of 25% in much of southern Africa in the UKTR scenario for the 2050s. Within the region, however, some areas experience a similar decrease in variability. The temperature-precipitation-$CO_2$ forcing of seasonal drought probably is less significant than the prospect of large-scale circulation changes that drive continental droughts that occur over several years. A change in the frequency and duration of atmosphere-ocean anomalies, such as the ENSO phenomenon, could force such large-scale changes in Africa's rainfall climatology. However, such scenarios of climate change are not well developed at the global level, much less for Africa.

The effects of drought are cross-cutting, with severe direct impacts on agriculture, water resources, and natural vegetation and indirect effects on health, the economy, and institutions (see Benson and Clay, 1994, for an overview of drought impacts). The impacts of drought are confounded by environmental degradation, including soil erosion, water pollution, and deforestation. Intersectoral linkages, the diversity of the economy, the numbers of vulnerable people, the intensity of water use in the economy, the role of financial systems and public enterprises, and public revenue and expenditure affect the severity and distribution of drought impacts. Drought in the 1960s, 1970s, and 1980s triggered widespread starvation and loss of life, particularly in the Sahel and the Horn of Africa. Similar famine has been averted in the 1990s through more effective early warning systems and responses. The aggregate impact of drought on the economies of Africa can be large: 8–9% of GDP in Zimbabwe and Zambia in 1992, 4–6% of GDP in Nigeria and Niger in 1984 (Benson and Clay, 1994).

The 1991–1992 episode in southern Africa amply illustrates the impact of drought. In that episode, the SADC countries experienced the worst drought of the century: From central Zambia through central Malawi and Mozambique southward, there were seasonal deficits of as much as 80% of normal rainfall (Zinyowera and Unganai, 1993). Large sections of the SADC subregion received scanty rainfall—20–75% of normal—during the rainy season from October 1991 through April 1992. Abnormally high temperatures (47°C along the South Africa-Zimbabwe border) exacerbated the extreme dryness. Regional grain production fell 60% short of expected levels. Food stocks had been depleted, largely as a consequence of exports. Roughly five times more food had to be brought into southern Africa than had been delivered to the Horn of Africa during the famine of 1984–1985. Six different transport corridors were used to deliver food aid, and 11 countries assisted in trying to alleviate the crisis wrought by the drought. Even though 1992–1993 and 1993–1994 could be considered post-drought periods, recovery in the subregion was slow. Nutritional status was affected by crop failure, depending on alternative sources of income and drought responses. The number of food-insecure households among communal farmers in Zimbabwe more than doubled during the 1991–1992 drought, especially in semi-arid zones (Christensen and Stack, 1992). The level of the reservoir at Kariba Dam, which supplies power to Zambia and Zimbabwe, fell below the level required to generate hydroelectric power (see IUCN, 1994). Water shortages, electricity shortages and rationing, input supply difficulties, reduction in demand, and macroeconomic constraints led to a 9% reduction in manufacturing output in Zimbabwe, with a 6% loss in foreign currency receipts (Benson and Clay, 1994).

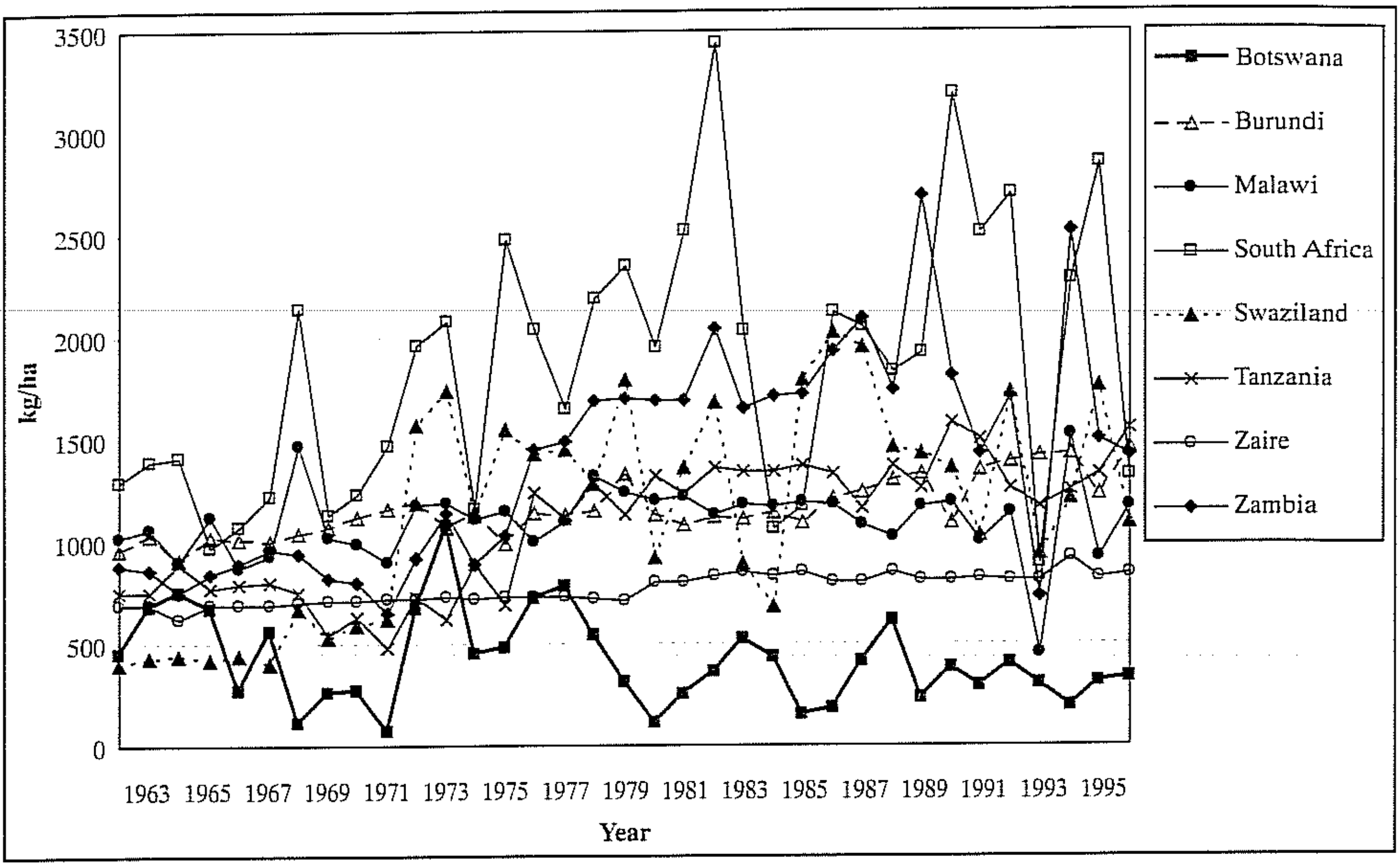


**Figure 2-13**: Maize yields in Africa (Hulme, 1996b), based on FAO data.

*et al.*, 1995; Hulme, 1996a; Ringius *et al.*, 1996), although an authoritative continental assessment has not been compiled. Global studies have included Africa—often, however, using poor data or inadequate spatial coverage and ignoring many critical issues of vulnerability and food security.

The general conclusion is that climate change will affect some parts of Africa negatively, although it will enhance prospects for crop production in other areas (see Downing, 1992, for case studies of agriculture in Kenya, Zimbabwe, and Senegal). Warmer climates will alter the distribution of agroecological zones. Highlands may become more suitable for annual cropping as a result of increased temperatures (and radiation) and reduced frost hazards. Although $C_3$ crops exhibit a positive response to increased $CO_2$ (as much as 30% with $2xCO_2$), the optimal productive temperature range is quite narrow. Some regions could experience temperature stress at certain growing periods—necessitating shifting of planting dates to minimize this risk. Expansion of agriculture is important in the east African highlands. For example, agroecological suitability in the highlands of Kenya would increase by perhaps 20% with warming of 2.5°C based on an index of potential food production (Downing, 1992). In contrast, semi-arid areas are likely to be worse off. In eastern Kenya, 2.5°C of warming results in a 20% decrease in calorie production. In some lowlands, high-temperature events may affect some crops. Growth is hindered by high temperatures, and plant metabolism for many cereal crops begins to break down above 40°C. Burke *et al.* (1988) found that many crops manage heat stress (with ample water supply) through increased transpiration to maintain foliage temperatures at their optimal range. Because a large portion of African agriculture is rain-fed, however, heat-related plant stress may reduce yields in several key crops—such as wheat, rice, maize, and potatoes. At the other extreme of the $C_3$ temperature spectrum, several crops (such as wheat and several fruit trees) require chilling periods (vernalization). Warmer night temperatures could impede vernalization in plants that require chilling, such as apples, peaches, and nectarines. Locations suitable for grapes and citrus fruit would shift to higher elevations. $C_4$ crops are more tolerant, in general, to climate variations involving temperature ranges between 25°C and 35°C. These crops most often are located in warmer, dryer climates; they are quite susceptible to water stress.

In Egypt, Eid (1994) evaluated wheat and maize sensitivity to warmer temperatures; Strzepek *et al.* (1995; see also Conway and Hulme, 1996) reported an integrated assessment of climate change impacts on coastal resources, agriculture, and water. The agricultural sector is highly sensitive to climate change, although different scenarios result in widely different impacts on irrigated agriculture.

In Kenya, a recent study by the International Institute for Applied Systems Analysis (IIASA) (Fischer and van Velthuizen, 1996) highlights the diverse effects of climate change. The Food

Agriculture Organization (FAO) Agroecological Zone [illegible] was used to delineate crop-growing regions and their suitability for a wide range of crops. Rising temperatures and increased plant water requirements would lead to dramatic reductions in agricultural production potential, especially in eastern and southern Kenya. In central and western Kenya, temperature increases would result in an extension of the land suitable for cultivation because some higher-elevation areas would become suitable for cropping. Along with higher cropping intensities in the highlands, this effect more than outweighs the effects of moisture stress in the lowlands. In humid regions (>270 days of growing periods), diminished wetness could reduce pest and disease constraints. The balance of increased evapotranspiration and precipitation in semi-arid regions determines the effect of climate change on agriculture and food security in the lowlands.

Using the ACRU/CERES hybrid model—one of the most sophisticated crop-climate models developed in Africa—Schulze *et al.* (1996) have evaluated the impact of climate change on maize in South Africa. The investigators divided the diverse geography of South Africa into 712 relatively homogeneous zones, each associated with vegetation, soil, and climate data. Daily values of temperature (minimum and maximum), rainfall, wind speed, and solar radiation are used in the crop evaluation, based on the CERES-Maize model. Recent scenario analysis of the model (see Hulme, 1996a) shows a wide range of potential maize yields in South Africa. For three scenarios of climate change (corresponding to the middle of the next century), yields decrease in the semi-arid west. For most of the country, however, potential yields would increase—generally by as much as 5 t/ha. The $CO_2$ enrichment effect counteracts the relatively modest changes in temperature and precipitation. In parts of the eastern highlands, particularly in Lesotho, dramatic increases in yields result from higher temperatures.

Hulme (1996b) presents an integrated view of climate impacts in southern Africa. Prospects for agriculture depend critically upon changes in precipitation. A "dry" scenario suggests less-suitable conditions in semi-arid and subhumid regions. With little decrease (or increases) in precipitation, agriculture should be able to cope with the average changes. However, shifts in drought risk need to be considered.

Ultimately, climate change is a global issue—even more so for traded commodities such as agricultural products. Some regions, for example, may be less competitive in national and global agricultural markets, with corresponding impacts on exports and imports. Africa, in particular, may be sensitive to changes in world prices and stocks because many countries rely on food imports. Several world-trade models have been tested with scenarios of climate change, with differing assumptions regarding economic growth, population growth, trade liberalization, and technological innovation (see Fischer *et al.*, 1994, 1996; Rosenzweig and Parry, 1994). Because they are global simulations, they can illustrate some of the dynamic adjustments in world prices and regional imports and exports that may result from climate change. However, Africa is not well represented in such assessments. Scenarios tend to be trend projections that discount the potential for dramatic improvements in agriculture or welfare. Moreover, the lack of uniform and accessible data on crop-climate sensitivity in Africa leads to large uncertainties in predicted impacts in Africa. A critical question is the extent to which climate change at the global level alters African exports (reflecting changes in comparative advantage) and food imports (reflecting the world price of cereals).

Most livestock in Africa are herded in nomadic areas, although significant numbers are kept in paddocks on farms. Domestic animals, especially cattle, also will be affected by climate change. In the cold highlands of Lesotho, for example, animals would benefit from warmer winters but could be negatively affected by a lowering of the already low nutritional quality of grazing. Heat stress also is a concern in warmer areas. The direct impacts of changes in the frequency, quantity, and intensity of precipitation and water availability on domestic animals are uncertain. However, increased droughts could seriously impact the availability of food and water—as in southern Africa during the droughts of the 1980s and 1990s (IPCC, 1996).

Agricultural pests, diseases, and weeds also will be affected by climate change. Little quantitative research on these topics has been undertaken in Africa, however. Perhaps the most significant shifts could occur in tsetse fly distributions and human disease vectors (such as mosquito-borne malaria). Tsetse fly infestation often limits where livestock can be kept or the expansion of extensive agriculture (Hulme, 1996a). Declining human health would affect labor productivity in agriculture.

African economies depend on natural resources, and the impact of changing natural resources affects several sectors. Perhaps more so than in many regions, the cross-sectoral impacts of climate change need to be understood. Agriculture depends on water resources, a healthy labor supply, and demand for its products. In turn, rural health, incomes, and development depend on viable agricultural economies. One example of the potential interactions is the role of drought. A small change in drought risk need not affect agriculture to a great extent, as long as food supplies and household income can be saved over several years. However, an increase in drought risk could affect regional water supplies, leading to rationing of water and energy and reduced irrigation. Increasing aridity and prolonged spells of severe drought could accelerate abandonment of the rural economy and migration to urban centers.

#### 2.3.3.2.3. *Adaptation and vulnerability*

Low investment in agriculture (see Table 2-7) means that African agriculture is extremely sensitive to climatic fluctuations. The current status of agriculture is not encouraging: It is characterized by stagnant yields, land degradation, and recurrent droughts (Box 2-7 suggests strategies to cope with current levels of climate variability and drought). Furthermore, political

### Box 2-7. Drought and Famine Responses

The loss of human life and economic disruption associated with extreme climatic fluctuation can be lessened by enhancing household coping strategies, preparedness, and advanced warning and timely responses. The initial aim in responding to drought is to maintain household livelihoods and mitigate the effects of rainfall shortages. Seasonal hunger, poverty, and household crises recur among vulnerable households throughout Africa. It is often difficult for governments, donors, and non-governmental organizations (NGOs) to distinguish between chronic conditions and an emerging crisis during a drought (or other shock). Recent scientific advances in understanding the climate system and predicting seasonal drought provide an opportunity to reduce the vulnerability of human societies (Rasmusson, 1987; Hastenrath, 1995; Bonkoungou, 1996). Predictions of seasonal rainfall already are operational in many regions of Africa, with lead times of up to several months. Longer-term forecasts also may be possible. However, drought predictions still need to be incorporated into African management of agriculture, water, energy, and national economies (see Gibberd *et al.*, 1996).

Increasing drought preparedness in Africa has resulted in a plethora of organizations that monitor climate, agriculture, vegetation, and resources; make available early-warning information; participate in multidisciplinary research; and promote preparedness plans. International early-warning systems such as the World Food Programme, the Food and Agriculture Organization, Save the Children Fund, U.S. Famine Early Warning System, and Agence Europèene pour le Développement et la Santé, among others, link local and national efforts with international responses. Following the devastating droughts of the 1970s in the Sahel, the AGRHYMET center was established in Niger. The SADC has a similar program on food security. Drought monitoring centers in Kenya and Zimbabwe and the African Centre for Meteorological Applications in Development were established in the 1990s. National departments, universities, and NGOs also have been active in promoting drought monitoring, mitigation, and preparedness. By monitoring key indicators of staple food production, national stocks, and import availability, a rough and ready national balance can be calculated using population estimates and per capita needs (SADC, 1996). Most famine early-warning systems (EWSs) predict the failure of food systems (Wilhite and Easterling, 1987). Increasingly, the focus of monitoring and intervention has been on food-insecure people who strive to subsist within food systems, rather than national food balances per se (Davies, 1996). Many EWSs now monitor upstream determinants of production (such as rainfall and soil moisture) as well as downstream outcome indicators (such as market prices for food and the nutritional status of those most vulnerable). Vulnerability assessment (and mapping) is one tool for integrating the climatic, production, and socioeconomic dimensions of drought in the context of sustainable development. Unfortunately, the focus often remains on food balances and food crises rather than solving chronic hunger and enhancing the livelihoods of the most vulnerable populations.

Early warnings do not guarantee effective responses. Early warnings by the drought monitoring centers and national meteorological services of a severe drought in 1991 were largely ignored by government and donor agencies (SADC, 1994). Economic structural adjustment programs failed to take rainfall variability into account in their design and emphasis on reform. Thus, numerous countries were poorly prepared, without a national disaster management program in place. There were conflicts over statistics used in emergency programs—where data from different sources were not reconciled—which led to delays in response. The response to the 1990s drought in Kenya was more positive; one month after the drought was apparent, large-scale food imports were made, and local food stocks were utilized (Longhurst, 1992; see Downing *et al.*, 1990, for a description of the similar success in 1984–1985). Preprogrammed drought responses also assisted in averting a major crisis: In northern Kenya, a decentralized early-warning system was well developed, and recommendations were translated rapidly into firm decisions to mitigate the impact of the drought.

Local coping strategies for drought and famine are well illustrated in the inner Niger delta of the Malian Sahel (Davies, 1996). Famine, although not entirely absent, is not a common occurrence in the Sahel. Periods of drought have been more frequent since the late 1960s, although there is little consensus regarding their origin or whether such drought is a permanent trend. Over the past 30 years or so, drought and famine have been part of a downward spiral of impoverishment, increasing vulnerability, destitution, and sometimes death. As a result of the Sahelian droughts of the early 1970s and the mid-1980s, fundamental changes are taking place in the livelihoods of people as they adapt to confront declining food security. Local livelihood systems have become less resilient and more sensitive (more vulnerable) to food stress with successive periods of drought. The nature and degree of vulnerability vary according to the livelihood system. Famines could be mitigated if policymakers can recognize and reinforce local coping strategies.

Lessons learned in responding to drought in Africa need to be widely implemented to reduce the threat of famine and enhance livelihood security. Promising developments in climate prediction and experience in early warning and responses lay the foundation for ending famine in Africa. Responses to drought also provide insight into effective adaptation to climate change. Reducing present vulnerability reduces the threat of catastrophic impacts. Institutional management of present climatic hazards should support adaptive learning to cope with future climate change.

conflicts have adversely affected food production, making the continent extremely vulnerable to climate change. Without a sound agricultural sector, Africa is unlikely to develop diversified economies that can cope with the impact of climate change. Thus, the impact of climate change on agriculture and food security in Africa over the next few decades will depend on progress in applied agricultural research and development.

There is a need for assessments of crops, agricultural systems, food economy, and food security at local, national, and regional levels, but data are not readily available (IPCC, 1996). In some African countries, such studies are underway.

Adaptation to climate change is not automatic or autonomous. The motivations, constraints, and domains of authority of decision-makers involved in shaping policy, implementing decisions, and coping with the consequences of changes in resources and hazards must be considered (see Grimble and Chan, 1995). The principal stakeholders in African agriculture range from vulnerable consumers and subsistence producers to national and international organizations charged with planning, research, and relief (see Gibberd *et al.*, 1996, for examples in the context of seasonal climate prediction). Consumers are the ultimate stakeholders in adapting to climate change. For particularly vulnerable groups (such as resource-poor farmers, landless laborers, the urban poor, the destitute and displaced, or refugee populations), the outcome of strategies to adapt to climate change and climatic hazards may alter their livelihoods. Failure to cope with adverse change could lead to significant deprivation, social disruption, and population displacement. Producers adapt to climatic variations every season but have varying interests in climate change. Subsistence farmers are unlikely to have the resources necessary to consider specific strategies to adapt to climate change. Commercial farmers are more likely to be linked to national markets and international agribusinesses and able to invest in agricultural technology. However, adopting specific strategies depends on cost effectiveness within the context of short-term enterprise goals. One of the key stakeholders in enacting forward-looking strategies is business—from local market traders to international commodity and research organizations. However, commodity traders are not likely to be affected directly by the consequences of climate change, as long as production is viable and trade required somewhere in the world. Incentives may be required to induce agribusiness to adopt a longer planning horizon and to develop and implement adaptive responses. At present, the bulk of responsibility for designing, evaluating, and implementing strategic responses falls upon national governments, national and international research centers, and aid organizations (particularly bilateral and multilateral groups, although some international and even local NGOs may take an interest in adaptation policies). These are the same actors charged with development; extending their purview to longer-term climate change should not be difficult.

### Box 2-8. Maize Adaptation to Climate Change in Zimbabwe

Throughout the world there is great scope to adapt to the agricultural impacts of climate change. Simulations with the CERES-Maize crop model at four sites in Zimbabwe illustrate the impacts of climate change and the effect of changing planting dates (Makadho, 1996; see also Muchena, 1994; Hulme, 1996b). The CERES model simulates crop development and yield using specialized functions to calculate photosynthesis, phenological stage, evapotranspiration, and partitioning of biomass. Simulations were discrete, with the default initial soil water moisture set at the field capacity of the soils. Nitrogen stress and pests were not simulated. Average potential yields, as simulated with 40 years of climate data, range from more than 3.5 t/ha in Region II (Karoi) to barely 1 t/ha in Region V (Beit Bridge). There is a considerable gap between these potential yields and the yields realized by farmers in the region. In semi-arid zones (Region V), 500 kg/ha would be an above-average yield. Average commercial farm yields in the high veld are closer to the potential yield because of application of fertilizer. For the two equilibrium scenarios of climate change, yields decrease in the high veld (Karoi) and semi-arid region (Beit Bridge) but increase in the middle zones (Gweru and Masvingo). If the season start is adjusted, the yield decreases in the high veld, and semi-arid zones produce sizable increases. For example, planting on 15 October at Karoi results in 3.7 t/ha at present. With climate change and delaying planting to 1 November, yields would be 4.6 t/ha—a 25% increase. At Beit Bridge, the season would shift toward earlier planting to avoid high temperatures and water stress at the height of the summer.

*Grain yield (kg/ha) from CERES-Maize simulations for Zimbabwe.*[1]

| | P Date | Present | CCC | GFDL |
|---|---|---|---|---|
| Karoi | 15 Oct | 3,727 | 2,643 | 2,940 |
| | 1 Nov | 3,654 | 4,641 | 4,630 |
| Gweru | 15 Oct | 3,006 | 5,011 | 5,446 |
| Masvingo | 15 Oct | 3,006 | 3,493 | 3,097 |
| Beit Bridge | 15 Dec | 1,213 | 713 | 725 |
| | 1 Dec | 1,203 | 1,304 | 1,453 |
| | 1 Nov | 1,136 | 838 | 1,740 |

[1] P Date is simulated planting date; CCC is the Canadian Climate Centre equilibrium GCM experiment, and GFDL is the Geophysical Fluid Dynamics Laboratory equilibrium GCM experiment.

Source: Makadho, 1996; see also Matarira *et al.*, 1996.

What options are available to different stakeholders to begin preparing for climate change in Africa? The impacts of climate change could be serious, at least in some regions and for some stakeholders. Equally important, however, climate change presents new opportunities that may promote development. Table 2-8 lists generic agricultural adjustments that currently are practiced in Africa and may be appropriate to cope with climate change. Adjustments are grouped according to the level of the agricultural sector in which they might be applied: land management, crop variety and land use, crop husbandry, and

*Table 2-8: Agricultural adjustments to climate change.*

| Strategy and Adjustment | Mechanisms | Costs | Implementation | Constraints and Issues |
|---|---|---|---|---|
| *Land Management* | | | | |
| Moisture management (conservation, irrigation, soil drainage, mulching, fallowing); soil management (mulching, tillage, crop rotation, land drainage) | Regulate soil water balance through incremental irrigation, drainage, control of evaporation, and runoff; enhance organic matter, use fertilizer, control soil erosion | Higher costs for additional irrigation works, water, operation, and maintenance; some additional labor and inputs | Gradual implementation with increased temperatures, often in response to drought | Water availability (surface and ground), water quality, terrain, alternative demands for water, investment capital and incentives |
| *Crop Variety and Land Use* | | | | |
| Cultivars; rotations; crop substitution; cropped area; crop location; conversion to/from crops or pasture; changes in specialization; livestock types and levels | Switch varieties, crops, or rotations (longer maturing varieties, heat- and drought-tolerant, requiring less vernalization); more flexible cropping system with seasonal forecasts, spread risk; switch location (regional or within farm) to new climates or soils; change specialization (e.g., arable/pasture production); change resource intensity (e.g., stocking rate) | Costs include development of cultivars, livestock breeding, and restructuring for different farming systems; marginal costs may be minimal if encompassed in normal agricultural investment | Costs are staged or incremental, but related to rate of climate change and possible effects of severe episodes; new cultivars require 10–15 years to develop | Lead time to develop new cultivars; soil suitability and terrain in conversion to agricultural uses; delayed response to new conditions; need for additional information and training; availability of genetic material |
| *Crop Husbandry: Planting and Harvesting* | | | | |
| Timing of planting and harvest; plant mixed varieties; planting depth; plant density | Earlier/later scheduling with changed growing season or to shift timing of heat stress; flexible cropping system; plant deeper in drier conditions; thin crop in dry years to lower plant density and reduce competition for moisture | Few additional costs; shifts in labor requirements during season | Gradual adjustment with little lead time; possibly greater flexibility in response to seasonal or monthly weather forecasts | Availability of cultivars, changes in winter season, frost, soils, field accessibility due to wet conditions may limit applicability |
| *Crop Husbandry: Fertility and Pest Management* | | | | |
| Herbicides; pesticides; fertilizer application; nitrogen-fixing crops | Control weeds to reduce competition for moisture, nutrients, and light; control pests and diseases that limit plant growth, yield, or yield quality; nature, quantity, and timing of fertilizer affect plant uptake | Input costs increase in general; considerable savings possible for some fertilizer/crop regimes, but increased costs in other regions | Gradual adjustment with short lead time and rapid responses, except for new crops and invading pests, diseases, and weeds | Toxic and ecological concerns with fertilizer leaching; information to respond to new pests, diseases, and weeds; new crops |

*Table 2-8 continued.*

| | Mechanisms | Costs | Implementation | Constraints and Issues |
|---|---|---|---|---|
| *Economic Adjustments: Farm Level* | | | | |
| Investment in agriculture (equipment and machinery); farm inputs; savings and storage; labor and employment; off-farm purchases; food consumption | Increased investment in agriculture to increase yields; increased food storage to reduce variability in supply; increased savings and purchases to supplement storage; off-farm employment to support increased investment and food purchases; altered food consumption to cope with seasonal shortages, shifts to new varieties, economic crises, labor demands | Infrastructure for storage and marketing; operation and maintenance costs for storage; opportunity cost of off-farm employment; costs of new technology; additional costs in dry years for purchases, replanting, etc. | Gradual but variable related to yields; storage facilities minor on-farm; gradual shifts in employment, but sudden with extreme episodes | Limited by finance, technology, type of agricultural production, surplus, access to regional and international economics and trade |

farm-level economic adjustments (macro-economic and sectoral planning also should be considered). Box 2-8 evaluates one such adjustment in Zimbabwe.

Beyond improving agriculture using available strategies, what more should be done to plan for climate change? Ringius *et al.* (1996) provided guidelines on adaptation for agriculture and water in Africa (see also Downing *et al.*, 1996). Anticipating climate change may be warranted for projects with long life spans (e.g., irrigation schemes); where the marginal cost of adaptation is small or brings benefits regardless of climate change; for protection against extreme events; and to prevent irreversible impacts (e.g., preservation of biodiversity). For example, the most certain aspect of climate change is increased $CO_2$ concentrations. Efforts to enhance positive $CO_2$ responses in new cultivars may be worth the investment in plant breeding and agricultural technology, irrespective of projected changes in moisture availability. Strategic food reserves to buffer potential increases in the variation of local and national production might be relatively inexpensive at the international level but not warranted for most countries or at local grain banks. Drought early warning and preparedness could build upon the considerable improvements that already are underway in many regions of Africa, including making better use of seasonal climate predictions.

Protection against irreversible impacts or losses of valued resources may be warranted in some situations. Thus, if coastal erosion and sea-level rise threaten valuable coastal resources, protection measures may be cost-effective. For example, groundwater pumping may be required to lower the water table if saline intrusion affects agriculture in low-lying areas. It is unlikely that such projects are a priority in the near future. However, protection measures should be considered in the design of new development.

Regulation of resource allocation and development is deficient in much of Africa. Institutional and regulatory reform may be warranted to preclude development in areas that become increasingly hazardous (such as coastal zones) and to protect vulnerable communities (e.g., economic restructuring). Establishing priorities for development based on future land capabilities may be premature for most regions, but flexibility in development priorities should be retained and new information taken into account. For example, the ability of community groups to manage rapid resource changes may warrant further support. Market structures often support crops with a high level of risk and fail to support markets for drought-tolerant crops. Regulations that constrain free trade may increase the volatility of local markets and food supplies in response to climatic variations.

If the present scope for adaptation is limited, investment in research and education are warranted to develop new solutions and stimulate behavioral changes to accommodate climate change. For example, development of cultivars that optimize responses to $CO_2$ enrichment and development and testing of new cultivars suitable for a range of likely climatic conditions require improved research. Education on environmental issues is warranted, although it is probably too soon to undertake specific campaigns designed to adapt to climate change. However, a broad capacity to address environmental issues and communicate understanding to stakeholders is urgently needed. This capacity is even more critical in linking greenhouse gas abatement with sustainable development issues.

Beyond specific adaptive actions, institutions may need to be strengthened—for example, to enhance the productivity of natural resources, to increase the capacity to respond to developmental pressures and resource crises, and to improve environmental quality. Concerning drought, institutions need to make better use of climate information to cope with climatic risks and reduce vulnerability. These are ongoing development objectives, but further assistance is warranted in light of the risk of changes in climatic hazards.

Ringius *et al.* (1996) evaluate four ensembles of adaptive strategies at different levels of planning:

1) Farm-level adaptive responses include substitution of agronomic practices (changes in sowing date, planting density, cultivars, etc.); altered inputs (e.g., fertilizer, pest and weed control, crop choice); and agricultural development (soil and water management that requires more substantial investment). The priority stakeholder is the smallholder farming sector. Commercial farms would be less likely to need assistance in these sorts of adaptive strategies. On the other hand, these strategies are less likely to be effective for agropastoralists and pastoralism in general. Such farm-level agronomic improvements can be effective, can be readily implemented, and have few substantial constraints to their adoption.
2) At the national level, three strategies commonly are proposed:
   - Maintaining strategic reserves allows the government (or marketing bodies) to dampen price fluctuations and release food in emerging crises. Large national reserves have been held in the past, but have been reduced under structural adjustment agreements because of their cost.
   - Markets and trading conditions could be adjusted to promote private-sector responses to climate change and climatic variability. This strategy might take the form of tax incentives for carry-over stocks or bonds to smooth income between adverse and good trading years. This approach would build upon present efforts to reduce trade barriers, with some specific adjustments to accommodate climate change.
   - Promoting agricultural development in general would close the gap between research and practice. The need to adapt to climate change could be used as one argument for fresh initiatives in promoting adaptive agricultural research and development in Africa.

   The primary beneficiaries of such national adaptive strategies are consumers and commercial producers who depend on markets for food consumption. Market adjustments may entail some trade-offs between consumers and producers or between relatively prosperous farmers and vulnerable smallholders who may not have access to inputs and markets. Yet the potential for multiple benefits is high (except for strategic reserves, which are a burden on the economy). As a group, these strategies would be reasonably effective in preparing for climate change.
3) At the global level, some policies to prepare for climate change may be justified:
   - Climate change may require additional trade to smooth out fluctuations in national production. Maintaining international prices within acceptable limits would benefit poorer countries that might not be able to afford large imports in times of scarcity. In the transition toward a new climate, such an international capacity to prevent food deficits from becoming survival emergencies would appeal to the humanitarian goals of ending famine and reducing hunger.
   - Encouraging free trade between and among countries should stimulate agricultural markets in regions with a comparative advantage. This trade may be a major benefit to some countries and a significant cost to others, as the impacts of climate change alter traditional markets. In principle, free trade allows national surpluses and deficits to be accommodated more efficiently. Thus, supply and price fluctuations are buffered at the global level, widening the potential pool of responses to climate change.
   - International mechanisms to promote agrotechnology transfers to developing countries might focus on basic foodstuffs: wheat, rice, and maize. International agencies might license new technologies developed by biotechnology firms for dissemination and use in developing countries.
4) Reducing drought risk and societal vulnerability would provide greater resilience in coping with climate change. Concerted action is required in three areas: mitigation to reduce vulnerability, monitoring drought and vulnerability, and preparedness to respond effectively to emerging crises. Considerable progress has been made in the past decade; a further decade of development might reap substantial rewards in efforts to eliminate widespread famine and enhance livelihood security, at least in times of drought (see Downing *et al.*, 1996; Gibberd *et al.*, 1996). The priority stakeholders should be the most vulnerable socioeconomic groups affected by drought crises—although many levels of local, national, and international actors are required to implement drought monitoring, mitigation, and emergency responses.

These four broad strategies would promote African resilience in the face of present climatic risks and enhance Africa's capacity to adapt to climate change. In the next few decades, Africa must manage the transition from vulnerable subsistence agriculture to resilient, adaptive systems. If real progress is achieved, most regions and populations could cope with climate change over the next few decades. Climate change on top of continued vulnerability and agricultural crises threatens regional security.

The fundamental requirement for adaptation in Africa is to promote sustainable agricultural development—closing the gap between experimental yields and farm yields, overcoming constraints in markets, and providing rural infrastructure (credit, inputs, transport, etc.), which will enhance the capacity of the agricultural sector to contribute to local and national economic development. The overall aim should be to make the best use of climate as a resource for agriculture by enhancing the capabilities of agriculturists, agribusiness, and organizations to respond to climate variations and climate change. Perhaps the clearest specific objective at present is to prepare for climatic hazards by reducing vulnerability by way of developing monitoring capabilities and by enhancing the responsiveness of the agricultural sector to forecasts of production variations and food crisis.

### 2.3.3.3. *Marine and Riverine Fisheries*

The African nations possess a variety of lacustrine, riverine, and marine habitats with more than 800 freshwater and marine species. Ten ichthyofauna regions, based largely on present-day drainage systems, have been delineated for Africa (Lowe-McConnell, 1987). These regions are dominated by the Niger, the Nile, the Congo, and the Zambezi River systems; they also include several inland drainage areas associated with lakes (Hlohowskyj *et al.*, 1996). Among the riverine systems, the Congo River (including its major tributaries) contains the most diverse fish fauna, with about 690 species (of which 80% are endemic) (Lowe-McConnell, 1987). Lacustrine systems in Africa (particularly the Rift Valley lakes) contain the most diverse and unique fish assemblages found anywhere in Africa, if not the world. For example, Lake Malawi has more than 240 identified fish species (of which more than 90% are endemic), and another 500 or more species awaiting taxonomic identification (Lewis *et al.*, 1986).

Fish make up a significant part of the food supply in Africa (Hersoug, 1995). FAO (1993) estimates the total fish harvest potential at around 10.5 million tons: 7.8 million in saltwater fisheries and 2.7 million in freshwater fisheries. In a densely populated country such as Nigeria, as much as one-third of the protein supply comes from fish (Hersoug, 1995). Consequently, any fluctuation in the fish stock will impact planning and management. A reduction in fish stocks will have the greatest effect on countries that are heavily dependent on fisheries and cannot diversify easily into other activities; Mauritania, Namibia, and Somalia are examples of African countries in this category (Clarke, 1993).

The productivity of freshwater and sea margins has become stressed mainly by economic activities rather than climate variability. For example, the artificial opening of the sand barrier at the mouth of the Cote d'Ivoire River to clear floating weeds has allowed seawater to enter the lower part of the river and has changed species dominance (IPCC 1996, WG II, Section 16.1.1). On the Nile, the Aswan Dam so thoroughly regulates flows that the delta has become degraded ecologically. Local sardine populations that once thrived and provided food for the region have collapsed with the decline in production that depended on the strong surges of floodwaters and their pulse nutrients. The Sahelian drought is causing increased salinity in the lower parts of Senegalese rivers, but a dam erected near the mouth of the Senegal River to stop the rising salinity and ease severe problems in local agriculture prevents fish migratio (Binet *et al.*, 1995).

#### 2.3.3.3.1. *Vulnerability of fisheries resources*

The vulnerability of fisheries to climate change depends on the nature of the climate change, the nature of the fishery, and its species and habitats. Changes in climatic conditions such as air temperature and precipitation affect fisheries by altering habitat availability or quality. Specifically, fisheries habitats may be affected by changes in water temperature; the timing and duration of extreme temperature conditions; the magnitude and pattern of annual stream flows; surface-water elevations; and the shorelines of lakes, reservoirs, and near-shore marine environments (Carpenter *et al.*, 1992).

Mean annual air temperature is the most important factor in predicting lake fish production across latitudes. Alterations in seasonal climate patterns should change the population distributions in larger lakes. Large-lake fish production could increase about 6% with a 1°C rise in average annual air temperature (Meisner *et al.*, 1987; IPCC 1996, WG II, Section 16.2.1). Warm-water lakes generally have higher productivity than cold-water lakes, and existing warm-water lakes will be in areas with the least change in temperature. It is reasonable to expect higher overall productivity from freshwater systems.

Although changing rainfall patterns and flood regimes may have profound effects on freshwater fish, marine fisheries are likely to be affected more by elevated temperatures (Hernes *et al.*, 1995). The impacts of elevated temperatures could include:

- A shift in centers of production and the composition of fish species as ecosystems move geographically and change internally. This is in contrast to freshwater fish species—particularly in small, shallow rivers and lakes—which will have limited possibilities to adapt to the changes through migration.
- Economic values can be expected to fall until long-term stability is reestablished. Rapid changes resulting from physical forcing favor smaller, low-priced, opportunistic species that discharge large numbers of eggs over long periods.
- Where ecosystems shift position, national fisheries will suffer if institutional mechanisms are not in place that enable fishermen to move within and across present exclusive economic zone boundaries. Subsistence and other small-scale fishermen (who dominate in Africa) probably will suffer disproportionally from such changes (Everett, 1994).

#### 2.3.3.3.2. *Adaptation options for fisheries resources*

Adaptation to existing climate variability may demonstrate ways to deal with climate change. The following options are suggested for the fisheries industry (IPCC 1996, WG II, Section 16.3.1):

- Modify and strengthen fisheries management policies and institutions and associated fish population and catch-monitoring activities.
- Preserve and restore wetlands, estuaries, floodplains, and bottomlands—essential habitats for most fisheries.
- Cooperate more closely with forestry, water, and other resource managers because of the close interaction between land cover and maintenance of adequate fishery habitat. The adequacy of management practices in all sectors affecting fisheries (e.g., water resources, coastal management) needs to be examined to ensure that proper responses are made as climate changes.
- Promote fisheries conservation and environmental education among fishermen.
- In cases of species collapse and obvious ecosystem disequilibrium, restock with ecologically sound species and strains as habitat changes; great care is needed to avoid ecological damage.
- Develop aquaculture and tourism to make coastal communities better able to deal with uncertainties of climate change.

To reduce the possibility of fishery disruption, strict biological monitoring should be implemented, and properly enforced fishing controls must be instituted. These strategies would help keep stock-replacement levels stable in the face of physical stress caused by climate change and other environmental phenomena while meeting the growing demand for fish and fishery products by an ever-increasing population.

### 2.3.3.4. *Production Forestry*

Plantations of exotic species are a major source of wood for timber and paper industries in Africa; indigenous species (hardwoods) are used mostly for fuelwood, for charcoal production, and in traditional construction. Some indigenous species have very specialized uses, including making furniture, musical instruments, railway sleepers, and carvings. In such cases, natural stands are harvested by removing large and viable trees, with residual stands left to recover. It is likely that natural stands would take 60 or more years before they produce trees of harvestable size. Exotic species, on the other hand, can take less than 10 years to about 30 years to produce poles and sawtimber-quality trees. The most common introduced species are pines (mostly *Pinus patula*), eucalypts, and cypress (*Cupressus spp.*).

In the 1980s, fast-growing exotic plantations were regarded as the solution to Africa's dwindling fuelwood resources. Many projects performed poorly, however, because of poor species choice, lack of species trials, limited site characterization, and unforeseen pests (such as goats and termites). Conversion of extensive areas of woodland, shrub, or savannas to forest plantations has had ecological consequences that have not been fully assessed for Africa. Elsewhere, extensive plantations lead to increased transpiration and reduced runoff, so catchmen yields can be reduced. Although there are signs of this process in many parts of Africa, no data have been collected. Eucalypts, in particular, have been suspected of drying landscapes and lowering water tables (FAO, 1985).

In many countries in Africa, forest plantations are established in marginal areas (to avoid competing with agriculture), and often in complex terrain (mountainsides and plateaus). Soi erosion after timber harvesting leads to siltation problems i rivers and reservoirs and can cause serious problems in hydroelectric generation. Plantations traditionally have been managed to maximize financial returns. Erosion problems associated with clear-cutting and log extraction will need to be addressed in future silvicultural planning, especially where logging is being carried out in catchment areas that are important for drinking water or hydroelectric generation.

The widespread use of exotic conifer species has increased the incidence of exotic forest pests, such as aphid pests (Katerere, 1983). These include the Eurasian pine woolly aphid, *Pineus pini* (Macquart); the Holarctic pine needle aphid, *Eulachnus rileyi* (Williams); and the European cypress aphid, *Cinara cupressi* (Buckton). The cypress aphid was first reported in Africa in Malawi in 1986 (Chilima, 1991); by 1990, it had spread to several countries, including Kenya (Owuar, 1991). In Africa, the aphid attacks the exotic plantations of *Cupressus lusitanica*, as well as indigenous species such as *Juniperus procera* and *Widdringtonia nodiflora* (Mulanje cedar)—Malawi's national tree. In Kenya, about half of the approximately 150,000 ha of plantation forests is *Cupressus lusitanica*. The aphid thus poses a considerable threat to the timber industry (Orondo and Day, 1994). Data are being collected to assess the extent of damage and any correlations with climatic factors in eastern and southern Africa (Chilima, pers. comm.).

Plantations may be most vulnerable to climate change through increased stress resulting from drought, which makes conditions ideal for new or old pests and diseases. In a matter of a few years, an important species can be wiped out—before control measures are developed or new species found to replace it. No data exist on how plantation species in Africa might respond to increases in $CO_2$ concentrations. It would seem likely, though, that improved WUE associated with a $CO_2$ fertilization effect would boost productivity.

### 2.3.4. *African Coastal Zones*

The African coastal zone consists of a narrow, low-lying coastal belt. It also includes the continental shelf and coasts of 32 mainland countries. It is composed of a variety of ecosystems, including barrier/lagoons, deltas, mountains, wetlands, mangroves, coral reefs, and shelf zones. These ecosystems vary in width from a few hundred meters (in the Red Sea area) to more than 100 km, especially in the Niger and Nile deltas. In west Africa (Mauritania to Namibia), the coastal a broad range of habitats and biota and includes the pristine islands of Bijagos Archipelago; the offshore island nations of Cape Verde and Sao Tome and Principe; and the remote central Atlantic islands of San Helena and Ascension.

A large percentage of west Africa's urban population lives in coastal cities. In Nigeria, for example, about 20 million people (22.6% of the national population) live along the coastal zone; about 4.5 million Senegalese (66.6% of the national population) live in the Dakar coastal area. About 90% of the industries in Senegal are located within the Dakar coastal zone. In Ghana, Benin, Togo, Sierra Leone, and Nigeria, most of the economic activities that form the backbone of the national economies are located within the coastal zone. Coastal areas also form the food basket of the region. Offshore and inshore areas, as well as estuaries and lagoons, support artisinal and industrial fisheries accounting for more than 75% of fishery landings in the region.

The coastal zone of east Africa, including coastal wetlands, extends from Sudan to South Africa and includes the near-shore islands off the coast of Tanzania and Mozambique and the oceanic islands of Madagascar, the Seychelles, Comoros, Mauritius, and Reunion. The desert margins of the Red Sea feature some of the richest coral reefs in the world. Coral reefs further south, extending from Kenya to the Tropic of Capricorn, are well distributed around most of the oceanic islands. They buffer the coastline against the impact of wave breakers and the full force of storms and cyclones. Many principal east African cities are located inland. Despite their low densities, however, coastal cities like Dar es Salaam and Mombasa are experiencing annual population growth of 6.75% and 5%, respectively (World Bank, 1995a). Coastal tourism and fisheries represent large inputs into the GNP of east African states.

Coastal population pressures and increasing exploitation of coastal resources—utilizing conflicting exploitation methods—have led to coastal degradation. Coastal erosion, flooding, pollution (air, water, land), deforestation, saltwater intrusion, and subsidence are some of the environmental problems degrading large parts of the coastal area of Africa. Coastal erosion already has been reported to reach 23–30 m annually in some parts of coastal west Africa (Ibe and Quelennac, 1989). In Cote d'Ivoire, high erosion rates have been reported in areas off the Abidjan harbor. It also is estimated that about 40% of the mangroves in Nigeria had been lost by 1980 (WRI, 1990); about 60% of mangrove areas in Senegal also have been lost as a result of mangrove clearing, coastal erosion, and increases in the salinity of water and soil. Industrial pollution from oil spills and discharge of domestic untreated wastes is polluting large areas of the coast, including lagoons and near-shore areas. The Korle lagoon in Accra, Lagos lagoon, and Ebrie lagoon in Abidjan all have been polluted, resulting in loss of fisheries resources.

Under doubled $CO_2$, climate change is projected to adversely affect several physical, ecological/biological, and socioeconomic characteristics of the west African coastal zone and adjacent oceans that presently are under stress. At the same time, population pressures and conflicting policies of exploitation of coastal resources also have had adverse effects on coastal sustainabili Environmental problems degrading the coastal area are project to increase as a result of either sea-level rise or an increase extreme weather events (IPCC, 1996).

### 2.3.4.1. *Vulnerability and Impacts of Climate Change on Coastal Zones*

Climate change will exacerbate existing physical, ecolog cal/biological, and socioeconomic stresses on the Afric coastal zone. Most existing studies focus on the extent to whic rising sea level could inundate and erode low-lying areas increase flooding caused by storm surges and intense rai storms. The coastal nations of west and central Africa (e.g Senegal, The Gambia, Sierra Leone, Nigeria, Cameroo Gabon, Angola) have low-lying lagoonal coasts that are su ceptible to erosion and hence are threatened by sea-level ris particularly because most of the countries in this area ha major and rapidly expanding cities on the coast (IPCC, 1996

Africa's west coast often is buffeted by storm surges and cu rently is at risk from erosion, inundation, and extreme stor events. Inundation could be a significant concern (Awosika *al.*, 1992; Dennis *et al.*, 1995; French *et al.*, 1995; ICST, 199 Jallow *et al.*, 1996). Major cities such as Banjul (Jallow *et a* 1996), Abidjan, Tabaou, Grand Bassam, Sassandra, San Ped (ICST, 1996), Lagos, and Port Harcourt (Awosika *et a* 1992)—all situated at sea level—would be very vulnerabl Finally, tidal waves, storm surges, and hazards also ma increase and may modify littoral transport (Allersman an Tilsmans, 1993).

The coastal zone of east Africa also will be affected—althoug unlike west Africa's Atlantic coast, this area experiences cal conditions through much of the year. Along the east coast Africa, sea-level rise and climatic variation may decrease th attenuation of coral and patch reefs that have evolved alon major sections of the continental shelf. The lessening of th buffer effect as a result of climate change would increase th potential for erosion of the east coast. Increases in populatio growth rates in the principal coastal cities of east Africa, con bined with a likelihood of a 1-m sea-level rise, could crea conditions for significant negative impacts on tourism-oriente economies, ecology, and natural habitats of this area.

Existing literature provides information about the implicatio of sea-level rise for Egypt, Nigeria, Senegal, Cote d'Ivoir The Gambia, and Tanzania.

#### 2.3.4.1.1. *Egypt*

Results from studies on various aspects of the impacts and po sible responses to sea-level rise on the Egyptian coast (Broadu *et al.*, 1986; Milliman *et al.*, 1989; Sestini, 1989; Ante, 199 El-Racy, 1990; El-Sayed, 1991; Khafagy *et al.*, 1992; Stank and Warne, 1993) indicate that a sizable proportion of th northern part of the Nile delta will be lost to a combination of inundation and erosion, with consequent loss of agricultural land and urban areas. Furthermore, agricultural land losses will occur as a result of soil salinization (El-Raey *et al.*, 1995).

Khafagy *et al.* (1992) estimate that for a 1-m sea-level rise, about 2,000 km$^2$ of land in coastal areas of the lower Nile delta may be lost to inundation. Substantial erosion should be expected, possibly leading to land losses of as much as 100 km$^2$. A very rough estimate of the agricultural land area that might become unusable is 1,000 km$^2$ (100,000 ha). With an average land value of US$1.5/m$^2$, the value of land loss in the lower Nile delta as a result of flooding alone will be on the order of US$750 million (2,500 million Egyptian pounds) (Khafagy *et al.*, 1992). Outside the delta, erosion is expected to be quite limited. If average erosion were 20 m along 50% of the remaining coast (and assuming land values on the order of 5 Egyptian pounds per m$^2$), the total loss would be about US$60 million (200 million Egyptian pounds).

For the Governorate of Alexandria, two main economic areas appear most vulnerable: the Alexandria lowlands and the Alexandria beaches (El-Raey *et al.*, 1995). The Alexandria lowlands—on which the city of Alexandria originally developed—are vulnerable to inundation, waterlogging, increased flooding, and salinization under accelerated sea-level rise. The two surviving Alexandria beaches (Gleam and El Chatby) will be lost even with a 0.5-m rise in sea level. Based on the 0.5-m scenario, estimated losses of land, installations, and tourism will exceed US$32.5 billion. An average business loss is estimated at US$127 million/yr because most tourist facilities such as hotels, camps, and youth hotels are located within 200–300 m of the shoreline. It has been widely reported that 8 million people would be displaced in Egypt by a 1-m rise in sea level, assuming no protection and existing population levels (Broadus *et al.*, 1986; Milliman *et al.*, 1989). This estimate is based on the displacement of 4 million people in the Nile delta, as well as the entire population of Alexandria.

### *2.3.4.1.2. Nigeria*

If sea level rises, inundation could occur along more than 70% of the Nigerian coastline, placing land at risk many kilometers inland (Awosika *et al.*, 1992). In Nigeria, inundation is the primary threat for at least 96% of the land at risk (Awosika *et al.*, 1992; French *et al.*, 1995). With a 1-m rise in sea level, up to 600 km$^2$ of land would be at risk. This area includes parts of Lagos and other smaller towns along the coast. For the Mud Coast, a 1-m rise will place as much as 2,016 km$^2$ of land at risk. Even with no acceleration in sea-level rise, current rates of land loss through edge erosion alone could cause losses of as much as 250 km$^2$ by the year 2100. This land loss is equivalent to an average shoreline recession of 3 km. Erosion threatens a higher percentage of the land on the Strand Coast than in the delta (4.6–20.7% for the Strand Coast, versus 0.8–3.5% for the delta). Without consideration of oil wells in the Niger delta, the greatest value at risk is along the Barrier Coast—ranging from just over US$1.3 billion with a 0.2-m sea-level rise to almost US$14 billion with a 2-m rise. When the value of the oil fields is considered, the value at risk increases from US$81.4 million to almost US$2.2 billion with a 0.2-m rise and from US$6 billion to more than US$19 billion for a 2-m rise. On the Strand Coast, a 1-m rise will result in a value loss of more than US$18 billion; the largest contribution to this loss would come from the oil fields in the area.

In Nigeria, a potentially massive "environmental refugee" migration will occur. For a 1-m rise, more than 3 million people are at risk, based on the present population. The estimated number of people that would be displaced ranges from 740,000 for a 0.2-m rise to 3.7 million for a 1-m rise and 10 million for a 2-m rise (Awosika *et al.*, 1992).

### *2.3.4.1.3. Senegal*

In Senegal, a 1-m rise in sea level could inundate and erode more than 6,000 km$^2$ of land, most of which is wetlands (Dennis *et al.*, 1995). In general, inundation is responsible for more than 95% of the land loss, independent of the scenario considered. Dennis *et al.* (1995) have shown that, under a 1-m scenario, buildings with a total market value of at least US$499–707 million would be at risk. On a national basis, tourist facilities represent 20–30% of the total value at risk under the 1-m scenario. Under the 1-m scenario, it is estimated that at least 110,000–180,000 people—or 1.4–2.3% of the 1990 population of Senegal—are at risk (Dennis *et al.*, 1995). Nearly all of these people are located south of the Cape Verde peninsula; the bulk of the population at risk lives south of Rufisque.

### *2.3.4.1.4. Cote d'Ivoire*

In Cote d'Ivoire, a 1-m sea-level rise will lead to inundation of 1,800 km$^2$ of lowland. The rate of shoreline retreat as a result of erosion is estimated to vary from 4.5 m to 7.4 m per annum (ICST, 1996). The most threatened infrastructures on the coastal zone are the Autonomous Port of Abidjan (Port Autonome d'Abidjan, PAA) and the port of San Pedro.

### *2.3.4.1.5. The Gambia*

In The Gambia, inundation is projected to lead to a loss of 92 km$^2$ of land for a 1-m sea-level rise. Shoreline retreat is projected to vary between 6.8 m in cliff areas to about 880 m for flatter and sandier areas (Jallow *et al.*, 1996). If a 1-m sea-level rise were to occur as envisaged, without protective measures the whole capital city of Banjul would be lost in the next 50–60 years because a majority of the city is below 1 m. Preliminary analysis of data from the Gambian Department of Lands on the value of land and sample properties between Banjul and the Kololi Beach Hotel suggests that about 1,950 billion Dalasis (US$217 million) of property will be lost (Jallow *et al.*, 1996).

All of the structures located on land between Sarro and Banjul cemeteries and the whole of Banjul will be lost. (It was not possible to attach monetary value to this loss of public places.) According to Jallow *et al.* (1996), the entire population of Banjul (42,000 inhabitants) and people living in the eastern parts of Bakau and Cape St. Mary—as well as the swampy parts of Old Jeswang, Kanifing Industrial Estate, Eboe Town, Taldning Kunjang, Fagikunda, and Aruko—will be displaced.

#### 2.3.4.1.6. *Tanzania*

Using sea-level rise scenarios of 0.5 and 1.0 m per century, Mwaipopo (1997) assessed the potential impacts of such a rise on the coastline of Tanzania. The results revealed that, with a 0.5-m and 1-m sea-level rise, about 2,090 km$^2$ and 2,117 km$^2$ of land would be inundated, respectively. With a 1-m sea-level rise, another 9 km$^2$ of land would be eroded. Projected damage is expected to be about Tsh. (Tanzanian shillings) 50 billion for a 0.5-m rise and Tsh. 86 billion for 1-m rise.

### 2.3.4.2. *Adaptation Strategies and Measures in the Coastal Zone*

Ibe (1990) has found that large-scale protective engineering measures are impractical in Africa because of the high costs to countries in the region. Instead, low-cost, low-technology, but effective measures—such as permeable, nonconcrete, floating breakwaters; artificial raising of beach elevations; and installation of rip-rap, timber groins, and so forth—are considered more sensible.

In Egypt, protection of beaches and associated infrastructure must depend upon continuous and periodic nourishment. The total cost of protection is estimated to be only US$21 million and $42 million for the 0.5-m and 1-m scenarios, respectively (El-Raey *et al.*, 1995). The city of Alexandria is built on three intermittent calcareous ridges, parts of which are leveled and thus constitute a potential pathway for rising water to reach the lowland south of the city. El-Raey *et al.* (1995) have suggested that maintaining the beaches in front of these pathways, using beach nourishment, will help to prevent surface water from reaching the lowland south of the city through these paths, particularly during storm surges. Construction of small dikes also may be necessary.

According to French *et al.* (1995), the potential cost of protection against a 1-m rise in sea level in Nigeria ranges from US$558–668 million if densely developed areas are protected (important areas protection) to US$1.4–1.8 billion if all shores are protected from erosion, inundation, and flooding (total protection). Under the "important areas protection" option, the 1-m sea-level rise scenario would require a total of 430 km of seawall and associated fill, costing nearly US$200 million. An additional 474 km of sheltered seawall and 180 km of open-coast seawall is required when total protection is considered. More than 600,000 villagers could be displaced by a 1-m rise in sea level, based on existing population (French *et al.*, 1995) It is impractical to protect these villages and populations at ris in Nigeria from a 1-m rise in sea level. Relocation probably i the most practical solution to the problem of inundation of th villages.

If the option considered in Senegal is "important areas protection," Dennis *et al.* (1995) suggest that about 70 km—or abou 14.5%—of the open coastline would require protection. Tota protection would require protection of 2,063 km, including 31 km of open-coast seawall and 1,680 km of sheltered-coast seawall. The cost of total protection is about 2.5–4 times highe than the costs of important areas protection.

With regard to The Gambia, Jallow *et al.* (1996) argue that i sea-level rise were to occur as envisaged, the most appropria response (considering The Gambia's economic situation would be to protect important areas. The projected cos includes US$3.1 million for construction of a 7-km low-cos seawall and US$3.9 million for construction of a revetmen About 16 km of dikes is required to protect villages borderin wetlands and swamplands from seasonal flooding. Four type of actions could fulfill required protection needs:

- Repair of groin systems
- Construction of breakwaters
- Construction of low-cost seawalls
- Construction of revetments.

In Cote d'Ivoire, the most essential response to a potential sea-level rise of 1 m in the next century would be to protect important areas—such as the two ports at Abidjan and San Pedro; th airport; tourism facilities; residential areas; and other areas o high economic importance, particularly in Grand Bassam Abidjan, Grand Lahou, Sassandra, San Pedro, and Tabo (ICST, 1996). No cost estimates are attached to this protection

Within an integrated approach, there is a great opportunity t anticipate problems associated with sea-level rise rather tha simply react to change as, or after, it occurs (Nicholls an Leatherman, 1994). Furthermore, a well-planned response tha seeks to anticipate the physical impacts of sea-level rise in a timely fashion will minimize unwise decisions and result i lower costs for reactive responses such as protection (Nicholl and Leatherman, 1995). Anticipatory responses include urba growth planning, building setbacks, wetland preservation an mitigation, public awareness, and integrated coastal zon management.

Policies and regulations concerning the use of the coastal zon for any form of human activity should include consideration o sea-level rise. Physical planning and building-control measure and regulations should be instituted and implemented Allocation of land for any economically useful purpose i areas likely to be flooded or inundated should be avoided. Th public should be informed of the risk of living in coastal an lowland areas that are threatened by sea-level rise. Timely public education about erosion, sea-level rise, and flooding risk could be a cost-effective means of reducing future expenditures. Where coastal infrastructures such as roads, fish land, and curing plants are approved and must be constructed, the authorities and owners of these infrastructures should make sure that marginal increases in the height of the structures are included to offset sea-level rise (Smith and Lenhart, 1996) and other related phenomena. People located in high-risk areas should be offered incentives to relocate out of these areas. Setbacks could be used as buffer zones to allow sea level to rise without threatening coastal development. French *et al.* (1995) recommended incorporating buffer zones between the shore and new coastal development in Nigeria.

Adaptation to climate change and concomitant adverse effects will involve an understanding of climate change parameters and dynamics, including monitoring and data analysis of climate change parameters. This strategy should lead to an African Climate Change Scenario (ACCS), upon which countries can base their adaptation options. Existing scenarios and adaptation measures for climate change and sea-level rise are built around Western experiences.

All of the adaptation strategies, options, and policies discussed above will reduce the risks from current climate variability and protect against potential climate change and sea-level rise. These measures should be combined in a coastal zone management plan (CZMP). The CZMP brings together all actors in the coastal area to address coastal-zone problems. The program should consist of a set of principles and plans to guide the use of coastal land for conservation, recreation, and development.

### 2.3.5. *Human Settlements, Energy, Industry, and Transport*

The pattern of distribution of human settlements often reflects the uneven nature of resource endowments and availability between regions and within individual communities. In Africa, as elsewhere, there are heavy concentrations of human settlements within 60 km of coastal zones, in areas of high economic potential, in river and lake basins, in close proximity to major transportation routes, and in places that enjoy hospitable climatic regimes. Changes in climate conditions would have severe impacts not only on the pattern of distribution of human settlements but also on the quality of life in particular areas. For example, wetter coasts or drier conditions in up-country areas could lead to spontaneous migrations as an adaptive option. Similarly, the pattern of energy use could change radically as a result of technological adaptations arising from climate change.

IPCC (1996) and UNFCCC (1992) acknowledge that developing countries' energy demands must increase to meet their needs for economic development. This increase must occur so these countries can respond to their development needs and to support the needs of growing populations. More of this economic development will be in industrial and transport sectors than in any other sector. It has been argued that the growth of the energy, industry, and transport sectors is needed as c
tries go through their economic transitions, which
decrease their vulnerability. Current high dependence on la
based production activities—such as agriculture and fi
eries—only increases the vulnerability of African countr
The energy, industry, and transport sectors are thus impor
in discussing vulnerability and adaptation.

#### 2.3.5.1. *Human Settlements*

The main challenges likely to face African populations
emanate from the effects of extreme events such as tropi
storms, floods, landslides, wind, cold waves, droughts,
abnormal sea-level rises that are expected as a result of clima
change. These events are likely to exacerbate manageme
problems relating to pollution, sanitation, waste disposal, wa
supply, public health, infrastructure, and technologies of pr
duction (IPCC, 1996).

Adaptation strategies lie mainly in relocating populations, ef
cient energy supply and use, introduction of adaptation tec
nologies, and improved management systems. Because most
these strategies have high cost implications, existing econom
constraints of African countries may present major obstacle
In addition, implementing some of these strategies may hav
aspects that go beyond costs; relocation of human settlemen
from low-lying coastal areas that are vulnerable to inundatio
for example, is likely to create problems that go beyond co
implications and include changes in social structure—clea
policies on land use, fortified by flexible land-tenure regime
will be needed.

#### 2.3.5.2. *Energy*

The impacts of climate change on the energy sector will be felt primarily through losses or changes in hydropower potential for electricity generation and the effects of increased runoff (and consequent siltation) on hydrogeneration, as well as changes in the growth rates of trees used for fuelwood. The total primary energy use in 1990 in sub-Saharan Africa (including South Africa) was broken down in the following shares: biomass fuels (53%), petroleum (26%), coal (14%), large-scale hydro (3%), natural gas (2%), and other renewables (2%). The most vulnerable areas of the energy sector to climate change in Africa are the provision of energy services for rural areas and, to some extent, for urban low-income needs. Table 2-9 shows that millions of cubic meters of wood are harvested each year for energy purposes. The extent of biomass dependence for the African energy sector is high; this dependence is critical because the source of biomass is supported only by the natural regeneration of indigenous natural forests. In addition to the primary energy sources listed in Table 2-10, dependence on charcoal is high in east and southern Africa, in countries such as Zambia and Tanzania; in Zambia, where charcoal provides 80% of urban household energy needs, 3.5 million tons of charcoal are produced annually from indigenous forests.

*Table 2-9: Relative extent of rural population in selected African countries and associated fuelwood production.*

| Subregion | Representative Country | Fuelwood Production ($10^3$ $m^3$) | Population ($10^3$) | Rural Population (%) |
|---|---|---|---|---|
| West Africa | Nigeria | 90,699 | 95,198 | 77 |
| | Ghana | 8,493 | 13,588 | 68 |
| East Africa | Kenya | 32,174 | 20,600 | 80 |
| | Ethiopia | 37,105 | 43,557 | 88 |
| Southern Africa | Zimbabwe | 5,988 | 8,777 | 75 |
| | Botswana | NA | 1,107 | 81 |
| North Africa | Sudan | 18,202 | 21,550 | 79 |
| | Egypt | 1,962 | 46,909 | 54 |
| Central Africa | Cameroon | 9,389 | 9,873 | 58 |
| | Chad | 3,137 | 5,018 | 73 |

Sources: Compiled from UNEP, 1990; ADB AEP, 1996.

In the household sector, fuelwood accounts for 97% of all energy consumed (Chidumayo, 1997). Although natural stocks of wood may be high, wood resources available to the majority of the rural population are very low in many areas. Brickmaking and tobacco and tea curing are major wood uses. In Zimbabwe, wood used for brickmaking is said to equal that used for cooking in rural areas (Bradley and Dewees, 1993); tobacco estates in Malawi account for 21% of total fuelwood consumption (Moyo *et al.*, 1993). In Botswana, the fencing of fields to keep out livestock consumes 1.5 times more wood than is used for cooking in farming households (Tietema *et al.*, 1991). Indigenous miombo and other woodlands in sub-Saharan Africa contribute significantly to the firewood harvested for consumption and conversion to charcoal. Stands are left to recover, with minimal active management. The ability of users to purchase alternative forms of energy (gas or electricity), as well as charcoal, depends on the economics of each family. Therefore, poor people (with limited buying power) are most vulnerable to reductions in fuelwood supply. Increasing populations also are contributing to depletion of resources. In relatively dense woodland areas, where population density is low, there usually is enough deadwood that can be collected and used for fuelwood. Increasing incidence of drought, however, leads to increased fire frequency—which, in turn, reduces deadwood material in woodlands. If current natural resource management systems are not changed, Africa could run the risk of depleting its forest resources used as biomass energy at a rate faster than the rate of population growth. The paucity of data on biomass depletion and regeneration rates makes meaningful assessment difficult and compounds the problems of possible reduced precipitation and subsequent lower regeneration rates by making it difficult to identify appropriate response options. There already are indications of a negative supply balance (e.g., extensive household utilization of agricultural and animal wastes for energy).

In 1992, Africa's electricity output was 312,000 GWh; thermal power provided 78% and hydroelectricity 19%, with a small amount (3%) from nuclear sources in South Africa (ADB AEP, 1996). Thermal power plants require huge volumes of water in their cooling systems; in a situation of reduced rainfall, loss of cooling-water resources will not only reduce generation capacity but also retard construction of new plants. It may be reasonably expected, therefore, that exploitation of the continent's massive coal reserves in areas with such resources would be inhibited by both the anti-coal lobby and shortages of cooling water. In the past (e.g., during the drought of 1991–92), declines in precipitation led to a significant loss of total hydropower energy, including losses of as much as 30% from the Kariba Dam (which supplies power for Zambia and Zimbabwe). It has been suggested that future hydropwer output could could be affected by climate change. Salewicz (1995) investigated the vulnerability of the Zambezi basin to climate change. He noted that 75% of the lower Zambezi waters flow into Kariba. Under climate change scenarios, this area is projected to experience increased rainfall and runoff into Lake Kariba. Although there may be shifts in the seasonal reliability of given discharges for the Lower Zambezi, it is possible that hydropower generation capacity would be adversely affected. Similar impacts could occur on the Congo, Nile, and Niger river hydropower systems, resulting in critical electricity supply shortfalls throughout the continent. In addition, the continent's massive hydroelectric potential of 150,000 GWh/yr would be significantly curtailed. Such a situation would lead to the introduction of major changes in fuel supply strategies in most countries. A case has been made for developing micro- and small-scale hydropower plants in Africa to overcome the cost of large-scale generation systems. This type of plant will require a defined minimum level of runoff. Reductions in precipitation could significantly reduce the number of viable sites for such micro-hydro installations.

*Table 2-10: Estimates of primary energy supplies (%) in subregions' representative countries.*

| Subregion | Representative Country | Oil | Coal | Gas | Biomass | Electricity/Hydro |
|---|---|---|---|---|---|---|
| West Africa | Nigeria | 27 | 0.4 | 12.6 | 59 | 1 |
| | Ghana | 21 | – | – | 69 | 10 |
| East Africa | Kenya | 21 | 1 | – | 70 | 8 |
| | Ethiopia | 8 | – | – | 90 | 2 |
| Southern Africa | Zimbabwe | 10 | 50 | – | 25 | 15 |
| | Botswana | 17 | 6 | – | 73 | 4 |
| North Africa | Sudan | 19 | – | – | 80 | 1 |
| | Egypt | 54 | 2 | 21 | 15 | – |
| Central Africa | Cameroon | 19 | – | – | 67 | 14 |
| | Chad | 33 | – | – | 77 | – |
| **Average** | | | | | 62.5 | |

Sources: Compiled and computed from UNEP, 1990; ADB AEP, 1996.

### 2.3.5.3. *Industry*

Changes in future climate should be actively considered in developing a sustainable industrial development path for Africa. Vulnerability in African industry may relate more to the inhibiting effects of climate change on industrial expansion than to its effects on existing industrial installations and investments. The most serious impacts of climate change on this sector would be related to loss of competitiveness associated with increased costs of production resulting from changes or retrofitting of plants for cleaner production. Reduced surface-water supplies would lead to extended use of groundwater sources—which, in most cases, have to be treated on site to achieve desired water-quality standards for specific industrial applications. Other major effects will result from a lack of water for industrial processes and increased costs of cooling for temperature-controlled processes and storage; Africa's industry has a large number of agro-industrial operations that need large amounts of water.

Besides these direct effects, there will be indirect effects, such as rising water costs; in cases of severe and recurrent water shortages, this factor could lead to relocation of industrial plants. Electricity shortages, due to a drop in the water level which causes a decline in hydropower, also will affect industry—particularly the steel sector (including iron and steel), ferro-chrome production, cement production, textiles, and aluminum production. These industries are among some of the most advanced on the continent, but they are highly dependent on constant electricity supplies. Although there are no data to indicate the level of water shortages that may result from a decline in precipitation, it is obvious that water shortages that affect concentrated urban settlements also will have a debilitating effect on industrial production. Water demand in many states in southern and northern Africa already has exceeded or is expected to exceed water supply soon.

Although detailed assessments of the impact of sea-level rise on coastal industries have been made for Asia and other regions, little information is available for Africa. It can be assumed, however, that most of the impacts that would ensue in other coastal zones would apply equally in Africa. Most impacts would be related to relocation of industries. The extent of these impacts could not be assessed in any detail without a more complete assessment of coastal zone industrial locations.

### 2.3.5.4. *Transport*

The transport sector is based on long-term, immovable infrastructure such as roads, rails, and water. In most parts of the continent, road networks have tended to link industrial centers with major areas of agricultural activity; railways have been designed in the past primarily with a sea-route orientation to facilitate international shipments of primary products. Climate change may lead to industrial relocation, resulting either from sea-level rise in coastal-zone areas or from transitions in agro-ecological zones. This relocation would necessitate additional infrastructural investments. It also may render waterways dysfunctional, thereby necessitating additional road and rail investments to replace them. If sea-level rise occurs, the effect on the many harbors and ports around the continent will be quite devastating economically for many coastal-zone countries. Excessive precipitation, which may occur in some parts of Africa, is likely to have serious negative effects on road networks and air transport. On the other hand, if climate change leads to drier conditions, maintenance costs may be reduced. Typical road networks on the continent consist of gravel roads linking major urban centers, which have paved road systems. Swaziland has a reasonable percentage of paved roads (55% by 1990). The situation is much worse in other countries, as indicated in Table 2-11, which shows the quality of road networks for selected African countries.

Agricultural production activities involve extensive transportation on the farm, to ferry farm products and inputs and to move farm implements. These critical operations are easily disturbed by excessive rains. The effects of such disturbances are likely to be higher in the case of large-scale commercial farms, which are highly mechanized. During recent droughts on the continent, soils on roads became friable as a result of high temperatures and dry weather. Such roads were easily washed away when the rains finally came, resulting in serious soil erosion and high repair costs to farmers. For small-scale communal land farmers, this situation was represented by massive soil erosion along pathways on and off the farm. In many cases, these washed-out pathways became the source of gullies.

Impacts on air transport would be greatest for airports located in coastal areas or near other water bodies, such as rivers or lakes. Indirect effects also would be felt if increased precipitation resulted from climate change, as some models have suggested. In this case, existing air transport support systems—such as meteorological data bases—may be stretched to their limits because they were designed for certain prevailing climates in the continent. Bad weather, in general, would raise the potential for air traffic accidents.

### *2.3.5.5. Mitigation and Adaptation: Response Options*

The suggestion that a "solar revolution" (Kane, 1996) ma replace the temporary fossil economy is rather simplistic. Fo African countries—which have yet to develop their infrastructure significantly and their basic industries—the need for centralized energy systems will continue for some time, althoug it may coexist with advances in solar installations. Besides thi general transition, Africa's centralized energy systems—including hydroelectric, coal, and oil thermal systems—wil need to benefit from cleaner, more efficient energy-conversio technologies. This transition will be based on autonomous efficiency improvements in the short to medium term, but Afric will not be in a position to drive trends toward such improvements, due to economic and technical trends.

Wind energy is a widely suggested option, based on average wind speeds of 5.8 m/s (Kane, 1996). Unless technologies are developed to generate electricity at lower speeds, the windmill option will remain limited in its application because wind speeds in the region generally are low, averaging 3–5 m/s.

New and renewable energy sources, however, offer other benefits in addition to being alternatives to large hydropower and thermal power generation systems. These alternative energy sources will generate more jobs overall in the economy. According to Kane (1996), these jobs will be high-quality jobs, mainly in systems design. For this reason, this benefit may remain limited in Africa because the continent lags other regions in the development of new technologies such as windmills, solar photovoltaics (PVs), and biogas digesters, which have been spearheaded in China and India. African countries should take immediate steps, with external support, to rectify this deficiency.

***Table 2-11****: Road networks and density for selected African countries.*

| Country | Paved Roads | % Paved | Total (km) | Density (km/1,000 km²) | Vehicles/km |
|---|---|---|---|---|---|
| Angola | 8,900 | 12.1 | 73,400 | 59 | 4 |
| Botswana | 3,740 | 20.4 | 18,330 | 32 | 4 |
| Ethiopia | 13,300 | 34.5 | 38,600 | 32 | 1 |
| Kenya | 9,800 | 14.5 | 67,800 | 117 | 5 |
| Lesotho | 540 | 11.2 | 4,840 | 161 | 5 |
| Malawi | 2,400 | 18.3 | 13,140 | 111 | 2 |
| Mauritius | 1,795 | 86 | 2,090 | 1,045 | 65 |
| Mozambique | 5,400 | 15.1 | 35,700 | 45 | 2 |
| Namibia | – | – | 6,500 | 8 | 21 |
| South Africa | – | 29.8 | – | – | – |
| Swaziland | 730 | 21.2 | 3,450 | 203 | 17 |
| Tanzania | 3,580 | 4 | 82,600 | 87 | 1 |
| Uganda (1993) | 8,342 | 21 | 40,057 | 166 | 2.4 |
| Zambia | 6,300 | 16 | 39,160 | 52 | 3 |
| Zimbabwe | 13,000 | 17 | 78,700 | 202 | 5 |
| **Average** | – | 23 | – | 166 | 10 |

Source: Zhou and Molcofi, 1997.

### Box 2-9. Cape Cross: The Ecological Importance of Coastal Wetlands

A number of African coastal areas, such as the Namibian coast, offer unique habitats for migratory bird species as well as a variety of local species (Williams, 1990). These wetlands are maintained by a complex hydrology of ephemeral rivers that flow onto the Namibian west coast. Changes in sea level would affect these western coastal wetlands through habitat loss.

Cape Cross, one of the earliest recorded (15th century) points of contact for European explorers in southern Africa, is best known for the large Cape Fur Seal (*Arctocephalus pusillus*) colony, numbering about 150,000 animals. To the south of the rocky promontory, a sand barrier has formed from sediments continually washed north from the Orange River. Behind this barrier is a series of lagoons, 5 km² in extent, comprising salt flats fed by seawater seepage and high-tide washovers (Williams, 1990). Wooden guano platforms were erected in these areas in the 1950s to allow cormorants to breed and roost (Rand, 1952). Guano is still harvested today from 30,000 pairs of Cape cormorants that nest there (Williams, 1990).

As many as 11,000 individuals of 28 species of coastal birds—including intra-African immigrants, palaearctic immigrants, and resident breeders—may be found on the lagoons (Williams, 1990). Among species listed as red data birds, more than 2,000 individuals of the southern African race of the black-necked grebe (*Podiceps nigricollis gurneyi)* may appear in these lagoons—about 16% of the estimated world population (Cooper and Hockey, 1981; Williams, 1990). The lagoons also regularly support between 1% and 3% of the southern African subcontinental population of greater flamingo (*Phoenicopterus ruber)* and lesser flamingo *(P. minor)* and up to 22% of the coastal population of Cape Teal (*Anus capensis)* (Williams, 1990). For palaearctic migrants, including the Curlew sandpiper (*Calidris ferruginea)*, the total number approaches 4,200 individuals; Cape Cross ranks about eighth in importance for these birds along the Namib coast (Williams, 1990). The Cape Cross seal colony falls within a national reserve and only limited disturbance occurs in the lagoons because of their inaccessibility. The area, therefore, suffers no current threat.

on tourism in these areas (Okoth-Ogendo and Ojwang, 1995). This effect could be exacerbated by disturbances in the pattern of human settlements in coastal zones and the general loss of environmental values.

Many tourist facilities (such as hotels) have been invested on inland lakeshores and reservoirs—such as Midmar Reservoir in South Africa, Lake Malawi, Lake Chad, Lake Victoria, and several other lakes in the Rift Valley in east Africa. In some cases, there also are downstream facilities, such as those on the Shire River and Liwonde. Past drought episodes have demonstrated that fluctuations in lake levels affect the quality of services that the lakeside resorts offer; the water level may recede a considerable distance from the facility. Lake Kariba currently is 13 m below its storage-capacity level; services such as dry-dock facilities have lain idle for several years. Figure 2-14 shows the changes in water level of Lake Kariba during the 1991–92 drought period. Where the lake is the primary source of an effluent river, river-based tourist facilities would be similarly prejudiced by lower lake levels. Such impacts would be more pronounced on reservoirs that combine other activities (e.g., irrigation or hydroelectric power generation) with tourism.

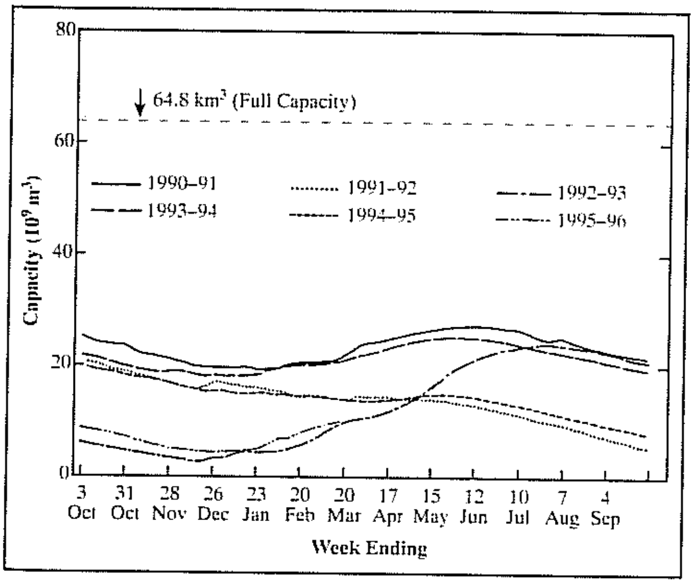


**Figure 2-14**: Lake Kariba water storage 1990–91 to 1995–96 (Hulme, 1996b).

An assessment of how the whole natural environment and wildlife might be susceptible to climate change should be an integral part of environment planning (Mkanda, 1996). A number of sub-Saharan countries regard the conservation of biological diversity (wildlife) together with agriculture and tourism activities as an important win-win solution to the nature resource that also offers a major source of much-needed revenue (World Bank, 1996). In a report on wildlife conservancies in Zimbabwe, Price Waterhouse (1994) demonstrated that wildlife presented the best land-use options in semi-arid parts of southeast Zimbabwe. This application, in the Gonarezhou nature reserve, has been facilitated by an appropriate legal framework in Zimbabwe—based on the Parks and Wildlife Act, which essentially confers stewardship of wildlife on landowners.

### 2.3.7. *Human Health*

The links between climate and many environmental and vector-borne diseases (VBDs) are felt through the impacts of various climatic components (e.g., temperature, rainfall) on the physiology of pathogens and their vectors. Although there are crude atlases of disease distribution within Africa (Knoch and Schulze, 1956), accurate and verified models that translate these physiological climate-related processes into more detailed maps of disease distribution are scarce. Such maps and models are necessary to set the baseline of current levels and limits of transmission against which projected impacts of climate change can be measured. These changes may include shifts in the distribution of diseases into areas that previously were disease-free or a change in severity at a given location. Although such models now exist (Martens *et al.*, 1995a,b; le Sueur *et al.*, in preparation), most remain hypothetical and largely unverified. However, they may provide good starting points to illustrate the effects of projected climate change. In the case of malaria, a continental effort—Mapping Malaria Risk in Africa (MARA/ARMA)—is now underway; this effor provide a data base of disease distribution and severit can be used to verify climate-induced processes. No parallel efforts, however, currently are underway for diseases of the African continent that may be affect climate change (e.g., arboviruses, trypansomiasis, schistosomiasis).

In Africa, VBDs are major causes of illness and death. 2-12 provides global estimates of the number of people a from and the number of people who currently are infect major VBDs. Currently, the distribution of most V remains well within the climatic limits of their vectors. extent to which disease transmission potential shifts graphically in response to shifts in vector distribution fol ing climate change will depend partly on how human ac ties modify local ecosystems (McMichael *et al.*, 1 Rodent-borne diseases that could be affected by cli change include plague and hantavirus pulmonary syndr In a warmer and more urbanized world, rodent populatio which act as pathogen reservoirs and as hosts for the rele

*Table 2-12: Major tropical vector-borne diseases and the likelihood of change in their distribution as a result of climate cha*

| Disease | Vector | Number at Risk (millions)[1] | Number Infected or New Cases/Year | Present Distribution | Likelihood of Altered Distributi with Climate Char |
|---|---|---|---|---|---|
| Malaria | Mosquito | 2,400 | 300–500 million | Tropics/subtropics | +++ |
| Schistosomiasis | Water snail | 600 | 200 million | Tropics/subtropics | ++ |
| Lymphatic filariasis | Mosquito | 1,094 | 117 million | Tropics/subtropics | + |
| African trypanosomiasis | Tsetse fly | 55 | 250,000–300,000 cases/yr | Tropical Africa | + |
| Dracunculiasis | Crustacean (copepod) | 100 | 100,000/yr | South Asia/ Middle East/ Central-West Africa | ? |
| Leishmaniasis | Phebotomine sand fly | 350 | 12 million infected, 500,000 new cases/yr[2] | Asia/South Europe/ Africa/Americas | + |
| Onchocerciasis | Blackfly | 123 | 17.5 million | Africa/Latin America | ++ |
| American trypanosomiasis | Triatomine bug | 100 | 18–20 million | Central-South America | + |
| Dengue | Mosquito | 2,500 | 50 million/yr | Tropics/subtropics | ++ |
| Yellow fever | Mosquito | 450 | <5,000 cases/yr | Tropical South America and Africa | ++ |

+ = likely; ++ = very likely; +++ = highly likely; ? = unknown.

[1] Top three entries are population prorated projections, based on 1989 estimates.

[2] Annual incidence of visceral leishmaniasis; annual incidence of cutaneous leishmaniasis is 1–1.5 million cases/yr.

Sources: PAHO, 1994; WHO, 1994, 1995; Michael and Bundy, 1996; WHO statistics arthropod vectors—will tend to increase. Thus, incidences of these diseases can be expected to rise (Shope, 1991).

Projected increases in the interannual variability of climate would have marked implications for the impact of seasonal epidemic diseases such as malaria. In general, control and mitigation activities for such diseases are planned around mean expected levels in any one year. Significant interannual variation impedes intervention and mitigation because of the impact on national budgets (which plan for mean circumstances) and lags that occur in relation to responses to climatically induced epidemic situations. In addition, such variation results in intermittent exposure of nonimmune populations—resulting in high levels of morbidity and mortality. The recent degree of variability is clearly illustrated in Table 2-13, which shows data for four southern African countries. This variability highlights the need for more climate-based forecasting systems capable of predicting such interannual variations with a lead time that allows health authorities to respond in a timely manner with preparatory/preventative measures (Jury, 1996; le Sueur and Sharp, 1996).

### 2.3.7.1. *Vulnerability and Adaptation*

It is projected that climate-related mortality will increase in the large cities of north Africa (IPCC, 1996), from direct effects as well as from indirect impacts of climate change. These impacts will include potential increases in the incidence of VBDs such as malaria, yellow fever, dengue fever, onchocerciasis, and trypanosomiasis arising from elevated temperatures and altered rainfall. High-elevation locations such as Nairobi or Harare may become vulnerable to malaria epidemics because the malaria parasite may be able to survive in the possibly warmer conditions (IPCC, 1996) at higher elevations than the current limits.

Minimum temperatures ($T_{min}$ or nighttime and winter temperatures) are crucial parameters for vector survival and affect the latitude and elevation of distribution, as well as the length of season permissive to transmission. $T_{min}$ is known to play a important role in limiting the distribution of malaria vecto populations at a given locality where summer conditions ar suitable for transmission (Craig and le Sueur, in preparatio Leeson, 1931). Thus, meteorological variables can create con ditions conducive to disease spread or even to clusters of ou breaks (in the case of flooding or drought) (Epstein *et al.* 1993). A drop in water level in dams and rivers also woul affect the quality of household and industrial fresh wat because reduced water volume would increase the concentr tion of sewage and other effluent in rivers—resulting in ou breaks of diseases such as diarrhea, dysentery, and choler During 1992 and 1993, cholera affected almost every countr in the SADC region, claiming hundreds of lives. In man drought-affected areas in Zambia, Zimbabwe, Botswana, an South Africa, streams and rivers dried up. Villagers (mainl women) had to walk long distances—only to collect pollut water, which they shared with wild animals and livestoc SARDC (1994) notes that when a major cholera outbrea occurred in several countries in southern Africa in the mi 1980s, the region had just come out of another drough Reduced water flow during these droughts reduced the capac ty of rivers, streams, and swamps to dilute agrochemicals an process fertilizers in fields, adversely affecting soil ecosy tems. These drought-related problems are likely to increas under projected climate change. Vulnerabilities and contr measures will affect the impact, however.

The growing resistance of insects to insecticides and microorganisms to antimicrobials, as well as the toxicity of pe ticides to helpful (predator) insects and larger animals (inclu ing humans), will limit the effectiveness of these control me sures. Thus, nurturing environmental conditions that redu vulnerability to VBD spread (e.g., extensive land clearing an monocultures), and those that shore up generalized defens (trees around plots and settlements to harbor birds that consum bugs) becomes increasingly important (Epstein, 1993, 1995).

In west Africa, the population of blackflies—which car onchocerciases (river blindness)—may increase by as much

*Table 2-13: Interannual variability of malaria (number of cases) within the southern Africa region.*

| **Country** | **1992** | **1993** | **1994** | **1995** | **1996** |
|---|---|---|---|---|---|
| Botswana | | | | | |
| (confirmed) | 415 | 14,615 | 5,335 | 2,129 | 19,340 |
| (unconfirmed)[1] | 4,293 | 40,722 | 24,256 | 15,470 | 49,315 |
| Namibia[1] | 238,592 | 386,215 | 407,863 | 286,407 | 353,593[2] |
| South Africa | 2,886 | 13,330 | 10,298 | 9,287 | 29,206 |
| Zimbabwe[1] | 420,137 | 877,734 | 797,659 | 721,376 | 1,585,850 |

[1] Clinically diagnosed.
[2] Incomplete.

25%, according to precipitation projections from the GISS GCM. Schistosomiasis and malaria, both of which depend on water availability, also are likely to increase as a result of projected expansion of irrigation in hot climates. African trypanosomiasis (sleeping sickness), which is carried by the tsetse fly, also could proliferate because higher temperature would increase the range of the vector in areas prone to this infection. The distribution of tsetse flies may increase in east Africa (Rogers and Packer, 1993). Other minor health effects could include higher incidences of skin disorders or cancers, cataracts and similar forms of eye damage, and suppression of immune systems as a consequence of stratospheric ozone depletion—which leads to greater ultraviolet radiation (IPCC, 1996).

Nutritional status also is likely to be severely affected by droughts and associated crop failures, as in southern Africa during the droughts of the 1980s to early 1990s. This factor will further reduce the natural persistence of African communities and increase exposure to disease.

There is increasing evidence that many emergent and resurgent diseases may be related to ecosystem instability (Epstein, 1995). In many cases, this resurgence may be related not to climatic change but to other human-induced changes in the environment (e.g., lyme disease, dengue, hantavirus) (Levins *et al.*, 1994; Wenzel, 1994; Epstein, 1995). Other diseases with clear links to climate and climatic change include malaria (Bouma *et al.*, 1994; Loevinsohn, 1994) and cholera (Epstein, 1992, 1995; Epstein *et al.*, 1993). Nonclimatic environmental modifications often disrupt natural habitats through processes such as deforestation or afforestation, resulting in the provision of new habitats for vectors or pathogens. Climatically induced change, however, can include short-term impacts as a result of interannual variation or long-term change associated with factors such as global warming. The effects of such changes are likely to be most noticeable in areas that constitute the fringes of distribution of a particular disease. Changes in distribution often will cause susceptible populations (those with little or no immunity) to be exposed to diseases not previously encountered—and result in severe morbidity and mortality. In addition, areas of traditionally low risk may become more vulnerable. The implications of such changes, especially in populations that lack immunity, have severe consequences (individual, social, and economic) for exposed individuals and health authorities.

Rogers (1996) modeled the effect of projected future climate changes on the distribution of three important disease vectors—mosquitoes, tsetse flies, and ticks—in southern Africa. The human diseases relating to these vectors are malaria (mosquitoes) and human African trypanosomiasis (tsetse flies). Climatic change may alter not only the physiological constraints placed on the vector but also the ability of the parasite to survive within the vector (Molineaux, 1988).

Within Africa, little evidence exists of causal changes in disease transmission and climate. This lack of evidence does not mean that these changes do not exist; rather, it may reflect the lack of available epidemiological data as a result of poor or absent surveillance and health information systems. Wi Africa, 71.3% of the burden of disease is attributed to in tious diseases; malaria is the single greatest contrib (10.8%). All other vector-borne, helminthic, and environm tally related diseases that are affected by climate contrib about 2% of the total burden of disease. With regard to en ronmentally related diseases in Africa, malaria contribu more than 80% of the cause of lost disability adjusted life y (World Bank, 1993; WHO, 1996b). These estimates excl diarrhea but include cholera.

Malaria contributes the highest percentage (>80%) of the mate-related disease burden in Africa. The physiological re tionships among climate, vectors, and pathogens are only p tially understood. Malaria provides a good example of h potential climate change may affect environmental and vect borne diseases. Surveillance systems and epidemiological d on malaria exist in some of the regions most susceptible to mate change, allowing future monitoring to move from spe lative to causal relationships.

One of the deficient micronutrients in malnourished Africans iron. Woman and children are disproportionately affected anemia, and pregnant women are especially at risk. In additi one of the major causes of death in acute and complicated mal ia is anemia. Thus, the potential exists for exacerbated morbi ty and mortality in regions in which climate change m decrease nutritional status and increase malaria transmission.

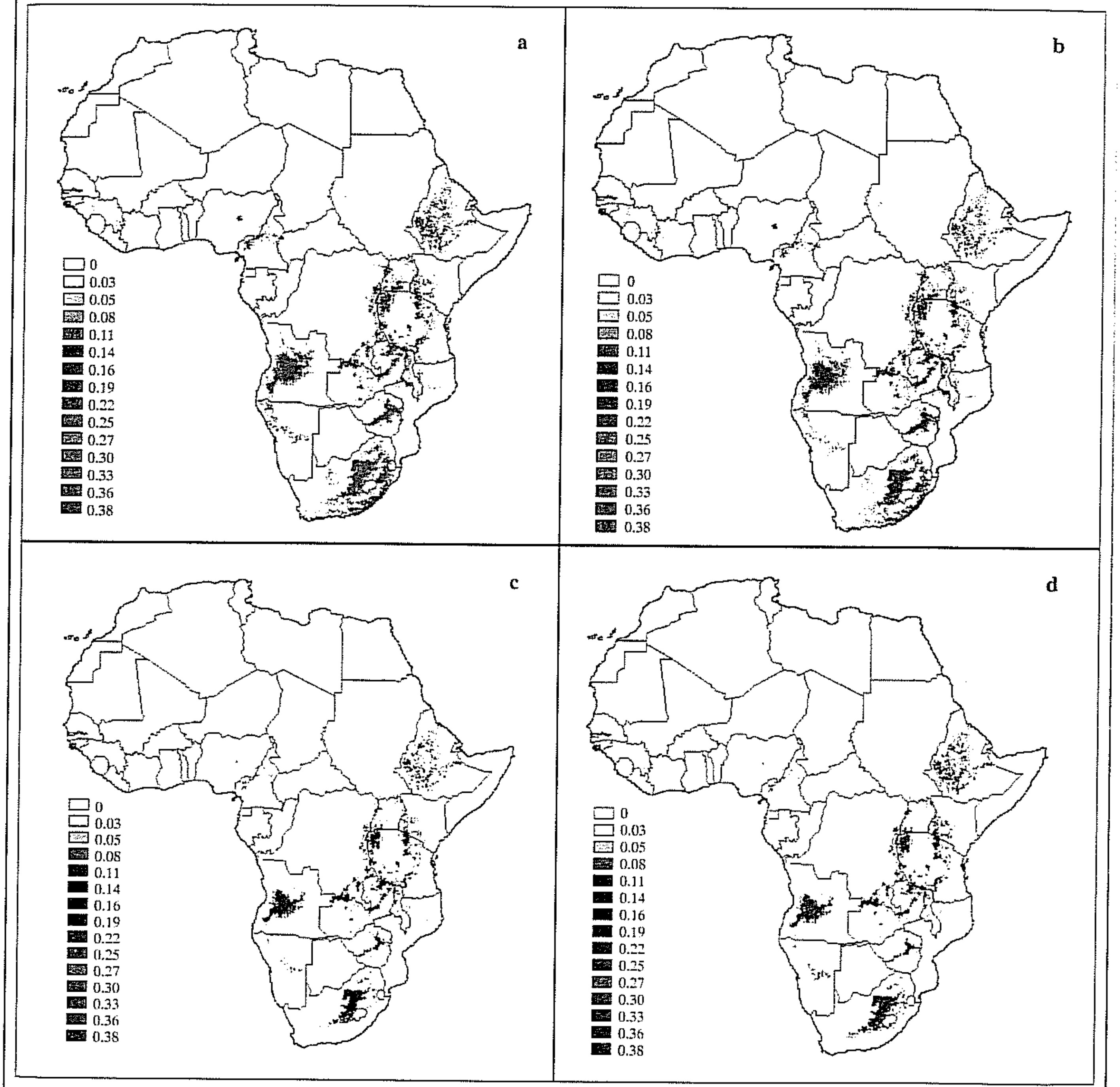
Climate-related impacts on health status are likely to increa most within Africa, largely as a result of the high burden of di ease within the continent and its vulnerability in terms of mi gation and nutritional status. In contrast to other regions of t world, a significant proportion of the burden of disease in Afri is related to climatically affected infectious diseases. Typical many of these diseases in Africa is the fact that their severi focuses within the tropics, and infection rates approach satur tion. Thus, the marginal regions of distributions, where severi of transmission is restricted climatologically, are most likely be affected by climatic change. It is important to distingui between restrictions related to rainfall and those related to ten perature. In cases where rainfall restricts distribution, increas in temperature may result in a decrease in disease incidence an distribution. Conversely, in areas where low temperature cu rently limits distribution, increased temperature may increa regional severity and cause distributional extension.

## 2.4. Integrated Assessment of Potential Impacts

Work on integrated assessment of climate change in the Afric region is in its infancy. Several different approaches are bein applied in country studies and primary research. Thes approaches include assessments of illustrative case example related to ecosystems, water supply/basin management, an socioeconomic activities such as agriculture. These case stud ies begin to integrate, for specific subregions (such as wate sheds or agricultural production areas), the impacts of clima

## Box 2-10. The Potential Impact of Long-Term Climate Change on Vector-Borne Diseases: The Case of Malaria

Malaria is a vector-borne environmental disease; as such, it is greatly influenced by macro- and microenvironmental changes. The impact of human-induced environmental change on malaria can be graded on a scale that commences at a global level and terminates at the level of an individual family homestead. In the investigation of environmentally induced changes in malaria transmission, it is impossible to restrict the study to localized environmental changes because they are nested within the changing macroenvironment. To understand the dynamics of these changes, as well as their interactions and their potential for prediction of occurrence, it is essential that we consider the role of macroenvironmental change (e.g., global warming) as well as microenvironmental change (e.g., deforestation or changes in land-use patterns, housing type, migration).



*Degree of Change: a) 5-month model with 1°C increase, b) 5-month model with 0.5°C increase, c) 5-month model with 0.5°C increase at elevation >1,300 m, and d) 5-month model with 1°C increase at elevation >1,300 m.*

### Box 2-10 continued

There is little doubt that global warming is now a reality (IPCC 1990, Chapters 5, 7, 8). Over the past three decades there has been a marked increase in mean temperatures, especially at higher latitudes; in the tropics, the increase is estimated to be about 0.2°C (IPCC 1990, Chapter 5). Some attention has focused on global climate change and its implications for epidemic malaria transmission (Bouma *et al.*, 1994; Martens *et al.*, 1995a; Martin and Lefebvre, 1995). The impact of these climatic changes on malaria is likely to be greatest in regions where malaria transmission previously was limited physiologically by low temperatures, which limit the development of the vector and the parasite. In these areas, transmission is likely to be limited to specific seasons (when temperatures are favorable) or may not occur at all. Increased temperatures will lengthen the transmission season, resulting in a marked increase in incidence. Increased temperatures also can expand transmission into regions that previously defined the limits of malaria transmission because of the effects of latitude or elevation (or both).

Studies in Rwanda (Loevinsohn, 1994) and Kenya (Knight and Neville, 1991; Some, 1994) have investigated the extent to which small-scale land-use changes can be responsible for dramatic increases in highland malaria. The effects of short-term environmental changes, as well as changes in human behavioral patterns (e.g., migration, changes in control activities in adjacent regions), are superimposed on more general effects of macroenvironmental change and are likely to play an important role in the onset of epidemics. Thus, although climate change may mean certain regions become more susceptible to malaria transmission, the actual risk of epidemics may remain low because of the absence of local contributory risk factors.

The accompanying figures a, b, c, and d provide a delineation of regions that would be environmentally affected by 0.5°C and 1.0°C increases in temperature. Figures a and b limit the modeling process to the highland areas of Africa, whereas Figures c and d include regions in which malaria distribution previously was restricted by elevation and latitude. These "new" zones of malaria transmission would be intermediate between areas of known annual transmission and those where malaria has never occurred. With respect to the latter (the upper limit), the simulation errs on the side of caution: Malaria always is limited (cannot occur at present) and is not subject to interannual variation. It uses existing long-term, retrospective, climatological (temperature and rainfall) and topographic surfaces that already exist for Africa (Hutchinson *et al.*, 1995). Inherent in the prerequisite for such epidemic fringe malaria (elevation or latitude) is that in certain years a window of suitable environmental conditions will exist. This window consists of a number of consecutive months with suitable environmental conditions. The graphic provides a conservative estimate; it assumes a prerequisite of five consecutive months, whereas in some regions (such as the Sahel) this may be as short as three (Bagayako, pers. comm.). Despite the occurrence of such a window, transmission may not occur. Transmission then will be contingent on human activities that result in the introduction of the parasite into this suitable (short-term) climatological environment.

The premise that climate variables, on their own, may not always reliably predict epidemic risk has important implications for the forecasting of epidemics and changes in distribution. This model is not definitive but provides an illustration of how climate may impact upon disease distribution and how regions of impact may be delineated. Similarly, the change or shift in severity in existing malarial regions could be modeled. The figures illustrate that increased temperatures would significantly increase susceptible regions in areas of the Southern Hemisphere where distribution previously was constrained by latitude. In contrast, northern Africa is not affected because the distribution concurs with the Sahelian region, where the absence of rainfall and high temperatures limits the disease (similarly with Botswana). Conversely, in certain areas of southern Africa, especially South Africa, low temperatures previously were limiting—thus, a significant increase in distribution is likely.

change with the potential impacts of other factors such as land-use change, demographic change, land degradation, air and water pollution, and economic and social change (including factors such as changing resource demands resulting from economic development and technological change).

The use of integrated assessment models has not been widespread in the African context, although it is becoming an item on the agenda of several modeling groups and organizations. More widespread use of integrated assessment models is a primary need and will require fundamental advances in the research literature. As a basis for integration, primary research on impacts on the potentially most vulnerable sectors and regions must be conducted so that interactions among the many potential costs and benefits can be assessed and, where possible, quantified.

## 2.5. Major Challenges Ahead for Africa

One of the first and most pressing scientific steps to address the possible) enhancement of the surface climate observing network. The network is important because, for the detection of long-term climate change, stable and continuous observing sites are necessary. The World Meteorological Organization (WMO) has a program to designate and maintain key sites as Reference Climate Stations. This program needs additional recognition and funding. The observing network also will help in the calibration of new satellite-based methods of observing the climate (WMO, 1992).

There is a continual need to evaluate the results of GCM experiments that simulate greenhouse gas- and aerosol-induced climate change to identify the likely subregional response within Africa to projected global-mean warming. This research should be seen as only one part of the much larger effort underway worldwide to narrow the uncertainties surrounding predictions of greenhouse gas-induced climate change. Determining whether recent desiccation in the Sahel is associated in some way with global air pollution also is of great importance (Hastenrath, 1995; Ringius *et al.*, 1996).

In addition to conducting more comprehensive assessments of the sensitivity and vulnerability of key resource sectors and systems, there is an urgent need to begin to apply existing and developing techniques for integration of potential climate change impacts on several dimensions, as suggested in the introduction to this report. These dimensions include:

- Integrating the chain of effects from changes in atmospheric composition and climate to changes in biophysical systems to the socioeconomic consequences (the "vertical" dimension)
- Including interactions among systems, sectors, and activities (the "horizontal" dimension)
- Considering climate change in the context of other trends and changes in society (the "time" or "global change" dimension)
- Considering the integrated impacts of current levels and episodes of climate variability.

In light of the large number and magnitude of socioeconomic and environmental changes projected for Africa, developing integrated assessments of climate change is an urgent priority for the region.

As this information on sectoral vulnerabilities and integrated assessment of potential climate change impacts is developed, it must penetrate more fully into national government organizations and international donor agencies. This penetration is necessary to ensure that what is known about past and present climate variability is properly taken into account in developing national economic and environmental plans (Sadowski *et al.*, 1996). Such sensitization of the policymaking process to climate variability also ensures that as knowledge about future climate change improves, it too can be sensibly used to guide drought/climate-related economic policy (OECD, 1996).

Within Africa, priority areas for environmental policy include securing sustainable water supply and quality; preventing and reversing desertification; combating coastal erosion and pollution; ensuring sustainable industrial development; making efficient use of energy resources; maintaining forests and wildlife resources; managing demographic change; and ensuring adequate food security. These priority areas highlight environmental and developmental concerns in the region that require immediate attention from the research and policy communities (Hulme, 1996a).

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